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APPLICATION OF A STATISTICAL MODEL FOR STABILITY OF PRODUCTION IN GRAIN SORGHUM SORGHUM BICOLOR (L.) MOENCH

by

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INTRODUCTION

Variation for stability of production across a range of environments has been recognized by plant breeders for many years. In the development of high yielding hybrids and varieties plant breeders have, to a considerable extent, directed their selection towards types that are adapted specifically to a given area or environment, and they are highly productive when grown in that area. The same hybrids or varieties may produce poorly, however, when grown in other areas or under less favorable environmental conditions. The development of types that give a stable performance over a range of environmental conditions would allow a given hybrid to be useful and productive in a larger region. Until recently, however, methods of analysis had not been developed that were specifically designed for evaluating stability of performance. Procedures have now been proposed which describe the mean of a variety in terms of estimated stability parameters. The use of these techniques greatly facilitates evaluations of the relative stability of different varieties or hybrids.

A concomitant question facing plant breeders has been what type of population structure is most desirable for the development of hybrids or varieties that will be widely adapted and highly buffered against environmental fluctuations. Populations which are made up of heterogeneous mixtures of heterozygous plants have proved useful in several crop species.

However, in the self-pollinated species populations have traditionally been homozygous and homogeneous, for example, the pure line varieties of small grains. Following the discovery of cytoplasmic-genic male sterility in grain sorghums, populations which are heterozygous and homogeneous have been developed and grown over a wide area. More recently multi-line oat populations which are homozygous and heterogeneous have been released for commercial production.

The objective of this study was to examine the relative performance for grain yield and its primary components among groups of grain sorghums, *Sorghum bicolor* (L.) Moench, that are representative of each of the aforementioned population types and determine which were the more productive and stable over a range of environments. Grain sorghums are particularly well suited for a relative evaluation of hybrid and pure line varieties because both types of populations are vigorous and reasonably comparable in their level of production.

REVIEW OF LITERATURE

Literature relevant to a consideration of the buffering capacity of plants against fluctuations of the environment includes some papers oriented primarily toward theoretical aspects and others which feature the presentation and interpretation of results from planned experimentation. Papers which deal largely with theoretical or procedural aspects will be reviewed first, followed by those which present the results of field experiments with grain sorghums and other agronomic species.

Lerner (1954) discusses homeostasis as an extension of Walter B. Cannon's concept of physiological homeostasis, and includes the self-regulatory mechanisms of an organism which contribute to a stable performance in fluctuating environments as an integral part of the concept. He suggests that the degree of adaptiveness of either individuals or groups in cross-fertilized species may be a function of their degree of heterozygosity. He further proposes that heterozygotes are more highly buffered in their developmental processes than are homozygotes, and suggests that this basis of buffering must be a function of some type of self-controlling model whereby alternate developmental pathways are available to the organism, with their use dependent upon genetic and environmental influences. The role of selection in maintaining heterozygosity in populations is considered particularly significant and

Schmalhausen (1949) is cited as defining stabilizing selection as the rejection by natural selection of the extreme deviates of the population.

Lewontin (1957) considers that there are two types of adaptation, namely, adaptation within a population and adaptation of a population. He defines adaptation within a population as the relative ability of individuals of a particular genotype to contribute offspring to succeeding generations. Adaptation of a population is then defined as the ability of a particular population, relative to other populations, to contribute offspring to succeeding generations. With these definitions the fitness or adaptive value of an individual or population must be associated with or defined relative to a specific environment. One population is considered to possess a better general adaptive value than another if it is adapted to a greater number of environments. Accordingly, a population which can adjust either its genotypic or phenotypic composition to afford survival and reproduction in a variety of environments should be referred to as a homeostatic population.

The concept of adaptation is discussed in detail by Simmonds (1962), and is defined as the property of a genotype which permits its survival under selection. He further divides adaptation into four categories, specific genotypic, general genotypic, specific population, and general population adaptation. Specific genotypic adaptation is defined as the close adaptation of the corresponding phenotype to a limited environment. This is cited as a common property of inbred annual species bred for high performance in a specific environment, for example, tomatoes for hot house production.

General genotypic adaptation is defined as the capacity of a genotype to produce a range of phenotypes adapted to a variety of environments. Exemplifications of this category are given for several plant species which show a wide adaptation of certain lines or clones. For example, the potato variety 'Majestic' which was bred in 1911 still comprises some 50 per cent of the potato acreage in Great Britain.

The definition of specific population adaptation is analogous to specific genotypic adaptation and is the specific adaptation of a heterogeneous population that is attributable to interactions among components, rather than to adaptation of the components themselves. This is a property of heterogeneous populations, that is, populations composed of mixtures of genotypes. Superior performance of the mixture relative to the properly weighted mean of the components exemplifies this type of adaptation.

Lastly, Simmonds (1962) defines general population adaptation as being analogous to general genotypic adaptation, and as the capacity of a heterogeneous population to adapt to a variety of environments. In general terms he refers to this capacity as stability of performance and considers that it should be measurable in terms of error variance. He cites numerous authors who have proposed that stability should be a characteristic of mixtures, and presents evidence from a number of experiments which supports this premise.

Bradshaw (1965) describes the concept of plasticity and discusses its use as a measure of the amount by which the expressions of individual characteristics of a genotype can be modified by its environment. He considers morphological and physiological plasticity as being interrelated, and suggests that the term stability can be used to describe the condition where there is a lack of plasticity. Both inherent stability of the species and plasticity of the components of yield are envisioned as contributing to the stability of performance sought by plant breeders. Differential reactions with several plant species to varying population densi ies are cited as evidence to substantiate his proposal.

Two ways for achieving stability of production over a range of environments are discussed by Allard and Bradshaw (1964). A variety can be composed of a number of individual genotypes, each of which is adapted to a different range of environments, or the variety can be composed of individuals all of which are alike but each member individually well adapted to a range of environments. The terms "individual buffering" and "populational buffering" are suggested as descriptive for the two stabilizing mechanisms.

Individual buffering is defined as the capacity of individual members of a population to exhibit a stable performance over environments as a result of buffering within the individual itself. Populational buffering, on the other hand, refers to buffering above and beyond that of the individual constituents of the population. Thus populational buffering can include individual buffering as well as buffering due to interactions of the coexisting genotypes. Therefore, buffering exhibited by a population comprised entirely of like genotypes must be a manifestation only of individual buffering, whereas buffering which is expressed beyond this level by populations made up of a number of different genotypes is termed populational buffering.

Allard and Bradshaw further point out that the aspect of genetic diversity that is associated with heterozygosity has been widely recognized and utilized in outbreeding species. They propose that the commercial experience with F_1 hybrid varieties of grain sorghum suggests that heterosis, and the individual buffering associated with it, exemplifies the substantial impact that can be made in increasing and stabilizing yields of self-pollinated species. They suggest that populational buffering is real and often important, even though there have been few conscious attempts to utilize it and little is known of its underlying mechanisms. The use of double cross hybrids in corn is cited as one example of widespread utilization of populational buffering. They elucidate some of the possible disadvantages of the use of mixtures or blends in crop species where uniformity of the product is a compelling factor, but also suggest that in some crop species it should be possible to develop blends which meet basic requirements for uniformity.

The development of multiline oat varieties composed of pure lines selected on the basis of uniformity of appearance, resistance to diseases, and other desirable agronomic characters was proposed by Jensen (1952) as a supplement to the production of new pure line varieties. Multiline varieties theoretically should possess a longer productive life, greater stability of production, broader environmental adaptation, and greater protection against disease than pure line varieties. He anticipated that small losses from disease infections would still occur, but maintained that the genetic diversity of multiline varieties would present an effective buffer system against a high incidence of any one disease. Changing the component lines of multiline varieties in recurring seed releases was proposed as an effective procedure for retarding the build-up of various races of the oat rust pathogens.

To predict the range of adaptation of potato varieties, Plaisted and Peterson (1959) developed a statistical technique for estimating the mean variety x location variance component of each variety in a test. Their technique consists of calculating a combined analysis of variance utilizing data from all varieties and all locations. If the variety x location mean square is significant they compute combined analyses of variance for all combinations of pairs of varieties, thus a test with n varieties will require the calculation of $n(n-1)/2$ analyses. The observed mean squares are equated to the expected mean squares to obtain an estimate of σ^2_{VL} from the analysis of each pair of varieties. Finally, the arithmetic mean of the estimates of σ^2_{VL} is calculated for all pairs of varieties having one member in common, and is designated the relative contribution of the common variety to the variety x location interaction obtained in the combined analysis of variance using all varieties. Any variety with a low contribution would be better adapted than a variety with a higher contribution to the variety x location interaction.

Finlay and Wilkinson (1963) studied the adaptation of a randomly chosen group of 277 varieties from the world barley collection for several seasons at three sites in South Australia. They developed a statistical technique for comparing the performance of a set of varieties grown in several environments. The technique consisted of measuring yield on a logarithmic scale and regressing the individual yield of each variety on the mean yield of all varieties at each environment. The mean yield of all varieties at each location and each season provided a numerical grading for locations and seasons and served as a means for comparative evaluation of the environments. With this procedure they were able to identify varieties adapted to good or poor seasons as well as those showing good general adaptability.

The two important indices of Finlay and Wilkinson's (1963) type of analysis are the regression coefficient and the variety mean yield over all environments, and their interpretive relationships warrant emphasis. Regression coefficients approximating to 1.0 indicate average stability. When this is associated with high mean yield, varieties have general adaptability; when associated with low mean yield, varieties are poorly adapted to all environments. Regression values increasing above 1.0 describe varieties with increasing sensitivity to environmental change (below average stability) and greater specificity of adaptability to high yielding environments. Regression coefficients decreasing below 1.0 provide a measure of greater resistance to environmental change (above average stability), and therefore increasing specificity of adaptability to low yielding environments. The second index, the variety mean yield over all environments, provides a comparative measure of performance of the individual varieties. Still wider interpretations from the two indices are attained by plotting them together as coordinates in a two-dimensional scatter diagram.

Among the 277 varieties evaluated they found wide variations in both mean yields and regression coefficients which indicates a variation in sensitivity to environments. Sensitivity to environment was proportionately less among varieties with the highest mean yields, and those varieties with the highest mean yields exhibited, within narrow limits, a similar degree of adaptation to all of the wide range of environments included in their study. Also, varieties from a particular geographic region of the world exhibited similar degrees of adaptation sensitivity.

Due to the inherent characteristics of their measurements the population mean has a regression coefficient of 1.0. The varieties which exhibited general adaptability for their environments all possessed slightly above average phenotypic stability, with b values of approximately 0.8. Phenotypic stability of the low yielding varieties in their experiments ranged from b = 0.14 to b = 2.13. An ideal variety was considered to be one which would have maximum yield potential in the most favorable environment and maximum phenotypic stability. In general, they found that the varieties having general adaptability fell short of the ideal. Varieties with high phenotypic stability had low mean yields and were so stable that they were unable to properly utilize high-yielding environments. Alternatively, some varieties were too sensitive to environmental change, as was shown by the low mean yields of some varieties with high regression coefficients.

Later, Finlay (1963) applied the same technique to hybrid populations of barley. He used the F_2 seed of 45 barley hybrids and their ten parent varieties in replicated trials over a three-year period. He found that the hybrids showed both an increase, in comparison with parental lines, for yield over all environments and a marked increase in phenotypic stability. Most of the parents exhibited below average stability whereas most of the hybrids displayed above average stability. The accentuated superiority of hybrids in the unfavorable environments accounted for much of the phenotypic stability of the heterozygous populations. Also, the superior performance of hybrids in all environments resulted in enhanced mean yields over all environments.

Yates and Cochran (1938) performed a similar statistical analysis on barley yield data collected over a two-year period at six experiment stations in Minnesota. The difference between the mean yield of each variety and the mean of all other varieties in a test was regressed on the mean yield of each experiment. Their purpose was to reveal relationships between general fertility and varietal differences, but they also suggested that similar procedures could be used to relate varietal differences with fertilizer applications or other treatments. Their procedure is not developed as fully for describing the adaptation response of varieties to a range of environments as is the procedure of Finlay and Wilkinson (1963).

Eberhart and Russell (1966) presented the model $Y_{ij} = u_i + \beta_i I_j + \delta_{ij}$ to express the relationship of stability parameters that can be used to describe the performance of a variety over a series of environments. Y_{ij} symbolizes the variety mean of the i^{th} variety at the j^{th} environment, u_i represents the i^{th} variety mean over all environments, β_i is the regression coefficient that measures the response of the i^{th} variety to varying environments, δ_{ij} is the deviation from regression of the i^{th} variety at the j^{th} environment, and I_j is the environmental index. They obtained I_j as the mean of all varieties at the j^{th} environment minus the grand mean for the entire experiment. They suggested that an index independent of variety effects obtained by considering such environmental factors as available moisture, temperature, and soil fertility would be desirable. However, until more precise knowledge of the relationships of these factors with yield permits the calculation of environmental indices on this basis, the average yield of all varieties in a particular environment will have to suffice.

They caution that in making evaluations of stability the varieties must be grown in an adequate number of environments, covering a wide range of environmental conditions, in order that meaningful information will be obtained. Three stability parameters are obtained with their procedure, namely, the regression coefficient, the deviations from regression and mean yield of the variety. The model permits a partitioning of the genotype x environment interaction of each variety into two parts, variation attributable to the response of a variety to the different environmental indices and the unexplainable deviations from the regression on the environmental index. They define a stable variety as one which has a high mean yield, a regression coefficient of 1.0 and deviations from regression approaching 0.0.

In the application of their model to single- and three-way crosses of corn they found that genetic differences were indicated for the regression of hybrids on the environmental index, with no evidence of nonadditive gene action. Estimates of the squared deviations from regression ranged from near zero to extremely large values for different hybrids.

They suggested that since the distribution of rainfall is a major environmental factor, early and late plantings can be used to obtain an extra environment at each location. Also, low and high plant density and fertilization can be used to increase the number of environments and perhaps also to increase the diversity of environments.

Scott (1967) defined a stable hybrid as a hybrid that exhibits the least yield variation over all environments tested. This type of hybrid would perform relatively well at low yielding environments but poorly at high yielding environments, therefore, it would have a relatively low yield potential. He then defined another type of stable hybrid as one that does not change its relative performance with other entries tested in many environments. This hybrid would yield as expected relative to other entries at each of many environments. Its regression on an environmental index would be 1.0 when analyzed by the methods of Finlay and Wilkinson (1963) and Eberhart and Russell (1966). Scott (1967) suggested that selecting for one type of stability automatically selects against the other type.

Lewis (1954) analyzed the relative stability of a homozygote and a heterozygote, using a theoretical model based on a single pair of alleles affecting a polygenic character. He concluded that a heterozygote which is more stable in performance than the homozygotes in two different environments is obtained when one allele is dominant in a particular environment and when that allele has an effect opposite to that of the environment. To test his theory he evaluated the expression of flower number in parental F_1, F_2, F_3, BC_1, and BC_2 populations of Lycopersicum esculentum in two temperature enivronments. Observations from these populations confirmed his predictions that greatest phenotypic stability would be shown by the F_1 hybrids in the two environments.

An investigation of the variability among eight inbred lines and six F_1 hybrids of tomato was conducted by Williams (1960). Relative magnitude of the nongenetic variability was examined for five quantitative characters. He reported that both inter- and intra-population variability exhibited by the hybrids was within the range of variability displayed by their parents. The data presented did not suggest any difference between the inbred lines and hybrids in buffering against environmentally induced variability.

Williams (1960) also examined the relationship of nongenetic variability with the mean and in four of eight comparisons found the level of variability to be significantly correlated with the magnitude of the mean. In two of the comparisons differences in variability could not be attributed entirely to differences in the means however, as different homozygous genotypes expressed different levels of variability regardless of the mean. In general, variability of the hybrids, expressed in standard deviation units, fluctuated around the mid-parent value. The low variability shown for flowering date seemingly was transmitted in a dominant fashion.

Probst (1957) evaluated three soybean varieties and 13 blends among them for seed yield, maturity, and lodging. In general, the blends were not superior in yield to the highest yielding component variety in any given year or for the average of four years. A stabilizing effect of the blends on yield was indicated by their low variety by season interaction. He observed that the latest maturing variety matured earlier when it was included as a component of a blend than it did when grown as a pure variety. Lodging scores for each blend, however, were similar to the lodging score of the most lodging susceptible component variety.

Competitive effects among three soybean varieties and their blended populations were examined by Mumaw and Weber (1957). They found that the average yield for blends involving two varieties was two per cent higher than the mean of the component varieties. They could not discern whether differences in maturity, height, or lodging were the most important contributors to the yield advantage. Generally, seed weights were decreased and seed numbers increased in the blends, relative to the mean performance of the components in pure stands. Although their yield results would not entirely discourage the use of certain blends, they concluded that in view of other agronomic considerations the use of soybean varietal blends could not be recommended.

Using Eberhart and Russell's (1966) model for evaluating stability, Smith et al. (1967) found that heterogeneous-homozygous soybean lines responded less radically to environmental changes than did corresponding homogeneous-homozygous lines. They defined a stable genotype as one which has a regression coefficient of 0.0 and deviations from regression of 0.0. They observed that genotypes which expressed above average stability were influenced less by changing environmental conditions than were those that expressed below average stability. In their experiments, low deviations from regression tended to be associated with regression coefficients which were below average. A positive correlation was observed between the mean performance of homogeneous daughter lines and heterogeneous maternal lines.

Heterogeneous and homozygous soybean lines performed equally well across three environments in experiments conducted by Byth and Weber (1968). They observed greater phenotypic stability for seven agronomic and chemical characteristics in F_2 derived lines than in F_5 derived lines. They believed that the greater stability was attributable to the greater heterogeniety within the F_2 derived lines, and that genetic uniformity within the F_5 lines resulted in large genotype by environment interactions for all characters studied. The lower variance among lines exhibited for all characters by the heterogeneous F_2 derived populations was attributed to homeostatic effects due to heterogeniety within the lines.

Allard (1961) reported on investigations with ten lima bean populations consisting of three pure line varieties, four mechanical mixtures of either two or three varieties, and three bulk populations obtained by propagating F_2 seed of variety crosses to the F_7 or F_9 generation. Tests were conducted during four consecutive years at four locations using randomized complete block designs with four replicates per location. He was interested specifically in determining if genetic diversity was related to productivity and stability of production.

Results showed that mechanical mixtures were consistently less productive but more stable than pure line varieties. The bulk populations yielded as well as the superior pure line parent and displayed about the same stability as the mechanical mixtures. He proposed that the superiority of bulk populations over the mechanical mixtures was not associated with heterosis alone, but was influenced by the ability of different genotypes to take full advantage of certain ecological sites and also by the elimination of poor yielding genotypes by natural selection during the bulk propagation of populations from the F_2 to the F_7 or F_9 generation.

He concluded that genetic diversity endows intraspecific mixtures with the ability to produce consistently regardless of the number of components or their morphological attributes. Although mixtures appeared to be insured against very low yields they were not necessarily endowed with high average productive capacity. Usually the bulk populations did not produce the highest yield in any given environment but were only slightly less likely to make exceptional yields than pure line varieties. He suggested that rational blends of pure lines chosen for uniformity of appearance and quality may increase the stability of production and also raise the yield of the blend above that of the best adapted variety.

In mixtures of parental and hybrid pearl millet seed Burton (1948) found that mixtures containing 90, 80, and 50 per cent hybrid seed yielded as well as the pure hybrid seed. In another experiment, using mixtures in conjunction with different plant densities, he found that when mixtures were sown in rows at rates of less than two plants per inch yield of the mixture was no greater than the weighted mean of its components. However, when plant density was from three to three and one-half seedlings per inch in the rows yield of the mixtures was comparable to that of the hybrids. Therefore, he concluded that plant density has an appreciable effect upon interplant competition within mixtures.

Engelke (1935) blended two varieties of wheat in different proportions and found that the yields of all blends were higher than the mean yields of the component pure line varieties, in some instances even higher than the highest yielding component. The number of plants per unit area also was higher in the blends, however, the weight of 1000 grains was unimproved.

Blending trials were conducted by Nuding (1936) in which the blends were made of all possible combinations of four wheat varieties taken two at a time. Included were varieties which exhibited large developmental and morphological differences. The results showed a tendency for blends to exceed the mean yield of their component varieties.

Pure line varieties of wheat together with their blended combinations were subjected to an analysis of yield characteristics by Frankel (1939). He found that although yields of the blends corresponded to expectations, based on performance of the component lines, the component varieties exerted modifying influences upon each other. One variety, Tuscan, demonstrated aggressiveness by depressing the yield of any line with which it was blended.

Shaalan et al. (1966) compared the grain yields of six pure line winter wheat varieties and four mixtures consisting of three varieties each for a seven year period. They included a newly reconstituted mixture each year as well as the original mixture. Results indicated that the annually reconstituted mixtures were more stable in performance than either the original mixtures or the component lines. They concluded that year-to-year variations for yield could be reduced by the use of annually reconstituted mixtures, but did not find average yields of the most agronomically desirable cultivars or the mixtures of similar phenotypic strains to be superior to the highest yielding cultivar.

Working with three related varieties of barley, Gustafsson (1953) found that number of spikes /plot was slightly but not significantly higher for blends in comparison with pure lines. Mixtures also were higher in number of spikes/plant, number of seeds/spike, total grain weight, and weight of 1000 seeds. Two of the three mixtures produced higher yields than the best component variety. He suggested that in the future small grain breeders may select lines which interact to improve the grain production of a composited population. Working with isogenic lines in other experiments he found instances where differences for simply inherited morphological traits affected the competitive ability of plants.

Competition has been defined by Sakai (1955) as the effect of interactions between individuals of different genotypes within a population. From experiments with five parental lines, ten F_1 hybrids and two tester varieties of barley he obtained individual plant data for heading date, culm length, plant weight, number of culms, and head weight. He concluded that the F_1 hybrids had a lower average competitive ability than their parents and showed that all of the parental varieties were higher in competitive ability than the tester varieties. Some of the hybrids were inferior to the tester varieties, and there were only a few cases where the hybrids surpassed the parental varieties in competitive ability. Sakai states that there is evidence for large genetic variations in competitive ability but thus far no association has been shown between competitive ability and visible morphological characters, although there may be associations with invisible morphological characters such as root growth. He suggests that the doubling of a basic chromosome complement lowers a plant's competitive ability, whereas allopolyploidy seems to enhance it.

Roy (1960) reported that when two rice varieties are grown as a mixture, or planted in alternate rows, or in separate halves of the same small plot and are surrounded by a dam, each may influence the yield of the other. Although cooperation does occur, the effect is as often unfavorable as favorable. In his most extensive study he found that the mean yield of two varieties in alternate row plots was 126 per cent of the mean yield when the two varieties were grown separately. He proposed that the favorable interaction takes place through or is associated with the water and the effect is lost if the area is flooded to the extent that the dams surrounding the plots are submerged.

Frey and Maldonado (1967) tested six oat cultivars and 57 mixtures among them for grain yield at both early and late planting dates. Mean relative yield of the mixtures in early plantings over a three year period was 100 per cent and at the late date mean yield of the mixtures was 104 per cent of the mean for all cultivars. They concluded that the advantage of heterogeneous oat populations increased as they were grown under conditions of greater environmental stress.

Only one mixture had a relative yield in the early planting that was significantly better than expected on the basis of mean performance of the component varieties, but at the second planting date eight of the mixtures yielded significantly more than anticipated. No association was observed between number of cultivars in a mixture and yield of the mixture. Several mixtures produced higher mean yields over the two planting dates than did their best component variety. Highly significant interaction variances were shown for dates x cultivars and dates x mixtures of two cultivars, but significant variances were not shown for dates x mixtures of three, four, or five cultivars. They concluded that mixtures of cultivars are more stable for grain yield over different planting dates than are the pure line cultivars.

In comparisons made by Patterson et al. (1963) among variety blends of oats, the blends were superior in standing ability but not in grain yield to the component varieties. Six varieties together with equal blends among them were grown for four years. They reported that genetic differences for maturity and height were no more important than other plant characteristics in affording the better standing ability of the blends and concluded that the use of blends might provide a useful interim procedure until improved pure line varieties could be developed.

Pfahler (1964) studied both fitness and the variability of fitness in seven oat populations consisting of six established varieties representing a range of morphological variation and a composite made up by mechanically mixing equal numbers of viable seeds from the six varieties. He was concerned with two components of the environment, the season and plant density. Populations were compared on the basis of mean number of surviving progeny as a measure of fitness and the variability of fitness produced by the environmental components. Differences in fitness among the varieties exceeded the one per cent level of probability and fitness of the composite exceeded the mean fitness value of the six varieties. He found no relationship between fitness and the variability of fitness among varieties, but the variability of fitness for the composite population was much lower than for any of the varieties. The distinct differential response of the varieties to the environmental components and their interactions was considered as evidence that the reactions were under genetic control.

Later, Pfahler (1965) reported on results obtained from experiments with oats and rye. He mixed two varieties of oats in 3:1, 1:1, and 1:3 proportions to produce three composite populations, and also mixed two rye varieties to produce analogous composites. Comparisons of the composite populations and component varieties were made in two years at seven plant densities thereby producing 14 environments. Mean grain and forage yields and variability in yield were evaluated in relation to years and population densities, and also in relation to time of clipping for forage yield.

Grain yields of all composite oat populations were not significantly lower than the yield of the more productive variety grown in pure stand, but they were significantly higher than the lower yielding variety. He found that variability in yield of the composites was appreciably lower than the mean variability of the two varieties, but not lower than the less variable variety. Both forage production and variability of forage production of the composites tended to change as proportions of the components were altered.

Grain production of the rye composites was approximately equal to the higher yielding variety. Variability in grain yield of the composites was considerably below the mean variability of the two varieties but higher than that of the less productive variety. Both forage production and variability of forage production showed the same trends that were observed in the oat populations.

In comparing yields of 317 single- and 483 double-crosses of corn, Jones (1958) observed that average yields of the two groups did not differ. The single crosses displayed a bimodal frequency distribution and a greater range in yield, however, than did the double crosses, whose frequency distribution was more nearly normal. Double crosses were more consistently high yielding and more desirable in other respects than the single crosses. He attributed the more consistent and stable performance of double crosses to their more genetically variable composition and suggested that hybrid mixtures may be equally as valuable for naturally self-fertilized species as crosses of inbred strains have been for cross-fertilized crops.

Stringfield (1959) tested 19 double crosses, four single crosses, and one open pollinated variety of corn individually and as paired mixtures in a single season. A measurable advantage or disadvantage for grain yield was not shown for the mixtures in comparison with the average of the components, regardless of the similarity or dissimilarity of the components.

Shank and Adams (1960) compared the performance of ten long-term inbred lines of maize with five of their F_1 hybrids for a two year period. For each character evaluated the inbred lines showed higher coefficients of variation than the hybrids. The variability within lines for a particular trait appeared not to be correlated with the variability expressed for other characters. Ranges for the degree of uniformity of inbreds and hybrids overlapped slightly. The coefficient of variability for the most uniform inbred was not appreciably larger than that of the most variable hybrid. A significant effect of seasons upon variability was manifested for all traits; however, inbreds usually were affected to a greater extent by seasonal conditions than were the hybrids. They concluded that heterozygous hybrids are more highly buffered against seasonal fluctuations than are homozygous lines.

Funk and Anderson (1964) investigated the effects of blending single cross hybrids of corn. They found that blending increased the stability of grain yield as indicated by a decrease in the entry by location interaction, but were not able to show a yield advantage for the blends over the mean of the component hybrids grown individually.

Estimates for stability of yield of 10 single- and 10 two-ear lines of corn in testcrosses with both one- and two-ear single crosses were compared in two experiments by Russell and Eberhart (1968). The stability parameters estimated for each of the four groups of hybrids were similar in the two experiments. Below average yields in the low yield environments and above average yields in the high yield environments were exhibited by the (1x1)x1 group, but the (2x2)x2 group displayed the reverse reaction. The (1x1)x1 group displayed the highest and the (2x2)x2 group the lowest deviations from regression. The (1x1)x2 group most nearly satisfied the definition of a stable variety on the basis of mean yields and regression coefficients. However, on the basis of deviations from regression the (2x2)x2 group was most stable.

Only one experiment evaluating the performance of mixtures of grain sorghums has been reported. Ross (1965) examined the performance of five grain sorghum hybrids grown individually and as equal blends of two hybrids. The blends were reconstituted each season and the experiment was grown in a six replicate randomized complete block design for five years at a single location. He found that the mean yield of all blends was not significantly different from the average yield of all hybrids grown individually. None of the blends gave a higher mean yield than the best hybrid, and in only one year did he find the mean of all blends to be significantly higher than the mean of all hybrids grown individually. That year was characterized as being extremely favorable for sorghum production. Examination of the individual year analyses showed that only two of the 50 blends deviated significantly from expected yields derived from mean performance of the component hybrids. For the five year means none of the blends deviated significantly from expectations based on mean yields of the component hybrids. Ross concluded that his data did not support the theory that mixtures of pairs of homogeneous grain sorghum single cross hybrids should perform advantageously under varied or stressed growth conditions. To the contrary, his experiments indicated that blends of sorghum hybrids perform best under optimum conditions.

MATERIALS AND METHODS

Plant Materials

The four male sterile (A) lines, their fertile non-restorer (B line) counterparts and the four pollen fertility restoring (R) lines selected for producing the hybrid and blended populations of grain sorghums used in this investigation are listed below:

A and B lines	R lines
Martin	Norghum
Combine Kafir 60	Texas 7078
Westland	Plainsman
Redlan	Caprock

All lines are homozygous recessive (dw dw) at three of the four loci described by Quinby and Karper (1954) as interactive in the determination of plant height in sorghums, and they range from early to late in maturity. Combine Kafir 60 is white seeded, the other lines are from light to dark red in seed color.

Hand pollinations were made using each R line as the male parent in combination with each A line to produce seed of the 16 F_1 single cross hybrids evaluated. Seed of each B line was mechanically mixed with each of the R lines to produce 16 parental blends with component line composition analagous to the parentage of the hybrids. Sixteen of the 120 possible two-component blends among the F_1 hybrids were selected randomly for inclusion in the experiment. Numbers were randomly assigned to each hybrid and then listed on both the horizontal and vertical-axis of a square. By taking combinations on a diagonal of this square each hybrid was represented twice as a component of a hybrid blend. The blended and hybrid populations together with the four B lines and four R lines provided a total of 56 entries for the experiment.

Before the seeds for planting were packeted, duplicate 100-seed samples of the parental lines and F_1 hybrids were germinated on moistened folded blotters in chambers of the Iowa State University Seed Laboratory maintained at alternating temperatures of 20° C. for 16 hours and 30° C. for 8 hours. Seed weights were taken on all samples before they were placed in the germinator and were used together with the germination percentages in computing equal numbers of viable seeds of the component lines for the planting of each blended population. Precise verifications of a 1:1 ratio of the components of all blends in the final stands were not attempted and would be nearly impossible for the blends involving similar morphological types. However, spot checks of blends in which the components could be readily identified by differences in seed color, head type or plant height indicated that the plant ratios were close to 1:1. Hereafter the mixtures of B and R lines will be referred to as parental blends and the mixtures of F_1 single crosses as hybrid blends.

Four types of structure or composition were represented in the populations evaluated. The parental lines were both homogeneous and homozygous, whereas the F_1 hybrid populations were homogeneous but composed of heterozygous genotypes. Both the parental and hybrid blends were heterogeneous in composition, with the component individuals of the parental blends being homozygous while those of the hybrid blends were heterozygous.

Plot Layout and Field Procedure

The experiment was grown in Iowa in 1966 and 1967 at the Iowa State University Agronomy Farm near Ames, the Western Iowa Experimental Farm at Castana, and the Shelby-Grundy Experimental Farm at Beaconsfield. In addition to the early or first planting at each location, late plantings also were made each year at Ames and Castana. Entries were arranged in randomized complete block designs with two replicates at each planting. Individual plots consisted of single rows 20 feet long, spaced 40 inches apart, with the central 16 feet used for yield and yield component determinations. The location, planting date, and the environment number assigned for each segment of the experiment are shown in Table 1. Hereafter, the text and tabular references to individual segments of the experiment usually will be made by environment number.

Planting at different dates at the same location was accomplished as a means for extending the range of environmental conditions encompassed by the experiment. The distribution of precipitation as well as temperature and light factors of the environment may differ considerably in relation

Table 1. Location planting date and environment number for each segment of the experiment

Location	Planting date	Environment number
Ames	May 25, 1966	1
Ames	June 14, 1966	2
Castana	May 18, 1966	3
Castana	June 7, 1966	4
Beaconsfield	May 26, 1966	5
Ames	May 24, 1967	6
Castana	May 23, 1967	7
Castana	June 21, 1967	8
Beaconsfield	June 20, 1967	9
Ames	June 20, 1967	10

to growth patterns of plants seeded at early and late dates. Table 2 lists the rainfall received at each of the three locations for both years of the experiment and the precipitation normally expected for the May-October period. Environmental differences also may be expanded through the use of different fertility practices. To this end, the sites for Environments 1, 3, 6, 7, and 9 were fertilized, before seeding, at rates of approximately 100, 80, and 80 pounds/acre of N, P and K, respectively. The experimental areas for Environments 2, 4, 5, and 8 were selected as being potentially less productive and were not fertilized.

A killing frost occurred at Ames on September 25, 1967 when an early morning temperature of 27° F. was recorded. Many plants in Environment 10 were just beyond the full bloom stage on that date. Therefore, a considerable number of the

Table 2. Precipitation received at the experimental sites from May through October in 1966 and 1967 together with 30-year means, 1930-1960

		Precipitation (inches)					
Location	Season	May	June	July	August	Sept.	Oct.
Ames	1966	4.81	8.56	1.28	2.03	0.25	0.51
	normal[a]	4.28	5.28	3.88	3.91	3.26	2.05
	1967	2.21	11.18	2.22	1.57	2.16	1.90
Castana	1966	1.93	6.91	2.78	2.77	1.60	0.45
	normal	3.79	4.80	3.47	3.34	2.59	1.70
	1967	2.00	13.62	0.92	1.37	1.45	2.13
Beaconsfield	1966	3.80	7.14	4.71	2.47	1.19	1.51
	normal	3.87	5.29	2.93	4.66	3.66	2.25
	1967	3.59	9.37	1.82	0.91	2.04	3.57

[a]Normal = 30-year average, 1930-1960

entries did not produce seed and Environment 10 was eliminated from the experiment.

The plots for all environments were seeded with a funnel planter and thinned when they were three to six inches tall to attain stands of four plants/foot of row. Thus the plant density for each environment was approximately 52,000 plants/acre. When plants were about one foot tall the central 16 feet of each row was staked and stand counts were recorded.

In general, the 1966 growing season was characterized by a very wet spring and early summer, followed by a dry late summer and fall. The spring season in 1967 was exceptionally dry until late May, when heavy and frequent rainfall occurred for a three week period. Abnormally cool temperatures prevailed throughout most of the summer and fall seasons, with freezing temperatures occurring at earlier than normal dates.

In October of each year, heads from each plot were severed with a knife, counted, placed in a loose mesh cloth bag, and dried at 160° F. for three days. Upon removal from the drier bags were hung in an unheated shed for approximately ten days before threshing to facilitate equalization of grain moisture content among all plots. The heads from each plot were then threshed with an Almaco plot thresher, and the threshed grain stored in cloth bags in the laboratory until weights were taken.

Collection of Data

Measurements were obtained for each plot for grain yield, number of heads/plant, number of seeds/head, and 100-seed weight. Number of heads/plant was calculated by dividing the number of heads harvested by the number of plants in the plot. Seed weights to the nearest centigram were determined by weighing 100 seeds counted from the threshed grain of each plot on a Mettler balance. Number of seeds/head was calculated by dividing the grain yield by the number of heads harvested and then dividing the resultant value by the average weight of a single seed.

Grain yields to the nearest gram were obtained by weighing the threshed grain from each plot on a Toledo balance. Grain moisture content was determined for several entries from each environment and found to be approximately five per cent for all maturity groups. Therefore, it was not necessary to adjust grain yields for moisture differences.

Statistical Analysis

The major portion of the statistical analyses were computed at the Iowa State University Statistical Laboratory. The descriptive model used initially for analyzing the data was written as follows:

$$Y_{ij} = U + A_i + B_j + E_{ij}$$

where: U symbolizes the grand mean; A denotes replicates; B represents entries; and E is the pooled error:

where: $i = 2$ and $j = 56$.

Individual analyses of variance and means were computed from the data obtained for each character at each environment. Coefficients of variation for each character and environment combination were calculated using the method outlined by Steele and Torrie (1960); i.e., dividing the square root of the error variance by the grand mean of the environment and multiplying by 100. Expected means for the blends were calculated by averaging the values obtained where components of the blends were grown individually.

Analyses of variance combining the data from all environments were computed for each character. The descriptive model for the combined analysis of variance was written as follows:

$$Y_{ijk} = U + A_i + B_{ij} + C_k + AC_{ik} + E_{ijk}$$

where: U represents the grand mean; A symbolizes environments; B denotes replicates; C designates entries; AC is the environment x entry interaction; and E is the experimental error:

where: $i = 9$; $j = 2$; and $k = 56$.

The sums of squares attributable to entries were partitioned for each of the individual environment analyses and for the combined analysis of variance into sums of squares within each of the following groups; parentals, hybrids, parental blends, and hybrid blends. Also in the combined analyses of variance the environments x entries interaction was partitioned into the interaction of environments with the analogous four groups, namely, environments x parentals, environments x hybrids, environments x parental blends, and environments x hybrid blends.

After partitioning the sums of squares for entries into the four groups three degrees of freedom remained for single degree of freedom comparisons. Three nonorthogonal but meaningful comparisons were chosen, namely, homogeneous versus heterogeneous populations, parental blends versus hybrid blends, and hybrids versus hybrid blends. Similarly after partitioning the entries x environments sum of squares the 24 degrees of freedom remaining were partitioned into eight degrees of freedom each for environments x (homogeneous versus heterogeneous populations), environments x (parental blends versus hybrid blends), and environments x (hybrids versus hybrid blends).

The procedures outlined by Eberhart and Russell (1966) were followed for analyses of the data and the calculation of stability parameters. The descriptive model defining the stability parameters was written as follows:

$$Y_{ij} = U_i + B_i I_j + D_{ij}$$

where: Y_{ij} represents the mean of the i^{th} entry at the j^{th} environment; U_i symbolizes the mean of the i^{th} entry over all environments; B_i denotes the regression coefficient that measures the response of the i^{th} entry to the different environments; D_{ij} is the deviation from regression of the i^{th} entry at the j^{th} environment; and I_j is the environmental index of the j^{th} environment:

where: $i = 56$ and $j = 9$.

The environmental indices were calculated using the following formula:

$$I_j = (\sum_i Y_{ij}/(2)(56)) - (\sum_i \sum_j Y_{ij}/(2)(56)(9)), \quad \sum_j I_j = 0.$$

Environmental indices determined for each of the character and environment combinations of the experiment are listed in Table 3.

For the analyses of variance when the stability parameters were estimated the sums of squares attributable to entries were partitioned into the sum of squares within each of the four groups, i.e., parentals, hybrids, parental blends, and hybrid blends. However, in contrast to the original analyses of

Table 3. Environmental indices obtained for the analyses of stability

Environment	Environmental index			
	Grain yield	Heads/ plant	Seeds/ head	100-seed weight
1	675.8	0.0425	-107.8	0.4362
2	-314.1	-0.0631	- 97.3	-0.1183
3	-447.5	0.1049	-598.9	0.2045
4	30.3	-0.0608	-103.1	0.2308
5	894.1	0.0264	44.4	0.5761
6	- 5.9	0.0050	157.2	-0.2085
7	572.1	0.0126	324.3	0.1870
8	-630.1	-0.0417	416.6	-0.7496
9	774.7	-0.0258	- 35.4	-0.5582

variance the three degrees of freedom remaining after this partitioning were not partitioned further as the pooled mean square provided the desired measure of variation between the four groups.

The hypothesis that the means for all entries are equal, $H_o:U_1=U_2=\cdots=U_{56}$, was tested by dividing the mean square associated with entries by the mean square associated with the pooled deviations and comparing the resultant value with the F distribution for the appropriate degrees of freedom. Similarily, an F test of the hypothesis that there were no differences among entries within a group was made by dividing the mean square associated with that group by the mean square associated with the pooled deviations for that group.

The hypothesis that there were no genetic differences between entries for their regression upon the environmental indices, $H_0: B_1 = B_2 = \cdots = B_{56}$, was tested by the F ratio resulting from dividing the mean square associated with entries x environments (linear) by the mean square associated with the pooled deviations. The comparable F ratio was calculated for each of the sub-groups partitioned from the entry x environment (linear) interaction.

To determine if the deviations from regression associated with each entry were different from zero the deviations from regression were divided by the pooled error and the resultant ratio was compared with the F distribution. Each regression coefficient was tested to determine if it was different from unity by the following t test as outlined in Steele and Torrie (1960):

$$t = (b-B)/\sqrt{S^2_{y \cdot x}/x^2}: \quad \text{where:} \quad B = 1.$$

For the grain yield data, predicted values were determined for the blends for each of the stability parameters by computing the arithmetic mean of the stability parameters estimated when components of the blend were grown separately. The stability parameters predicted for each blend were then correlated with those determined from the data obtained for the blended populations. Similarly, mid-parental values of the stability parameters were calculated for each hybrid and the predicted values were then correlated with the stability parameters determined from the data obtained for the hybrids. All correlations were calculated using the mean performance of each entry over all environments.

EXPERIMENTAL RESULTS

The data reported herein were obtained from the nine environments described previously. Mean yields for the different environments ranged from 63.6 bushels/acre (Environment 9) to 117.5 bushels/acre (Environment 5), with an average for all environments of 88.5. This range adequately spans, and transcends somewhat, the levels of productivity commonly encountered in sorghum yield tests in Iowa.

The individual analyses of variance for each environment, as well as the coefficients of variation for each character, are presented in Tables 4 through 12. For grain yield the highest pooled error was obtained in both years at the Beaconsfield location (Environments 5 and 9), whereas it was lowest in 1966 for the Castana late planting (Environment 4), and in 1967 at Ames (Environment 6). Some reduction in seed size among the late entries at Environment 9 was occasioned by the early frost and likely was a contributing factor to the high coefficient of variation for this test.

In each environment the mean square for grain yield attributable to entries exceeded the one per cent level of probability, indicating that the entries responded differently within each of the nine environments. However, when the entries' sums of squares were partitioned further to evaluate the variation exhibited within each of the four population types, the mean square for parentals was not significant at

Table 4. Analyses of variance for grain yield, heads/plant, seeds/head, and 100-seed weight for Environment 1

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Replications	1	228,874	0.0118	25,140	0.0108
Entries	55	400,549**	0.0106**	255,823**	0.1138**
Parentals	7	390,250**	0.0246**	224,433**	0.0529
Hybrids	15	501,348**	0.0112**	461,027**	0.1847**
Parental blends	15	177,423**	0.0077*	129,057**	0.0385
Hybrid blends	15	225,156**	0.0080*	158,437**	0.1389**
Homo.[a] vs. hetero.[b]	1	29,703	0.0009	22,825	0.0214
Parental blends vs. hybrid blends	1	3,515,625**	0.0030	668,715**	0.2717**
Hybrids vs. hybrid blends	1	44,310	0.0030	19,113	0.0127
Error	55	58,898	0.0040	34,034	0.0263
Coeff. of variation, %		7.08	5.46	9.73	6.25

*Significant at the 5% level of probability

**Significant at the 1% level of probability

[a]Homo. = Homogeneous populations (parentals and hybrids)

[b]Hetero. = Heterogeneous populations (parental blends and hybrid blends)

Table 5. Analyses of variance for grain yield, heads/plant, seeds/head, and 100-seed weight for Environment 2

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Replications	1	306,080*	0.0049*	500,626**	0.0302
Entries	55	191,609**	0.0010	165,048**	0.0682**
Parentals	7	149,650	0.0013	197,492**	0.0783**
Hybrids	15	141,682*	0.0005	186,787**	0.1103**
Parental blends	15	69,061	0.0012	98,139*	0.0371**
Hybrid blends	15	70,832	0.0011	82,499	0.0500**
Homo.[a] vs. hetero.[b]	1	73,616	0.0008	228	0.0369
Parental blends vs. hybrid blends	1	2,836,698**	0.0015	1,213,853**	0.1388**
Hybrids vs. hybrid blends	1	131,588	0.0010	1,722	0.0072
Error	55	72,510	0.0007	48,111	0.0135
Coeff. of variation, %		11.05	2.70	11.50	5.71

*Significant at the 5% level of probability

**Significant at the 1% level of probability

[a]Homo. = Homogeneous populations (parentals and hybrids)

[b]Hetero. = Heterogeneous populations (parental blends and hybrid blends)

Table 6. Analyses of variance for grain yield, heads/plant, seeds/head, and 100-seed weight for Environment 3

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Replications	1	160,136	0.0361*	499,691**	0.0010
Entries	55	517,222**	0.0224**	154,690**	0.1993**
Parentals	7	493,876**	0.0106	152,902**	0.4579**
Hybrids	15	377,869**	0.0356**	153,133**	0.1546**
Parental blends	15	248,197**	0.0106	141,016**	0.2354**
Hybrid blends	15	321,638**	0.0128	71,316**	0.1059**
Homo.[a] vs. Hetero.[b]	1	714,359**	0.0003	183	0.2379**
Parental blends vs. hybrid blends	1	5,524,263**	0.1378**	815,183**	0.0023
Hybrids vs. hybrid blends	1	202,275	0.0005	35,674	0.0141
Error	55	76,150	0.0086	26,330	0.0245
Coeff. of variation, %		11.98	7.87	11.55	6.63

*Significant at the 5% level of probability

**Significant at the 1% level of probability

[a]Homo. = Homogeneous populations (parentals and hybrids)

[b]Hetero. = Heterogeneous populations (parental blends and hybrid blends)

Table 7. Analyses of variance for grain yield, heads/plant, seeds/head, and 100-seed weight for Environment 4

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Replications	1	92,230	0.0665**	8,366	0.0054
Entries	55	284,800**	0.0063**	178,326**	0.0952**
Parentals	7	402,064**	0.0147**	215,833**	0.1010**
Hybrids	15	165,452**	0.0070**	211,826**	0.1513**
Parental blends	15	83,583*	0.0018	42,431	0.0578**
Hybrid blends	15	69,271	0.0070**	72,930*	0.0867**
Homo.[a] vs. hetero.[b]	1	205,564*	0.0003	1,177	0.0339*
Parental blends vs. hybrid blends	1	4,281,278**	0.0053	1,899,573**	0.0333*
Hybrids vs. hybrid blends	1	683	0.0011	2,957	0.0135
Error	55	39,994	0.0024	31,866	0.0061
Coeff. of variation, %		7.19	4.82	9.39	3.28

*Significant at the 5% level of probability

**Significant at the 1% level of probability

[a]Homo. = Homogeneous populations (parentals and hybrids)

[b]Hetero. = Heterogeneous populations (parental blends and hybrid blends)

Table 8. Analyses of variance for grain yield, heads/plant, seeds/head, and 100-seed weight for Environment 5

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	seeds/head	100-seed weight
Replications	1	2,353,187**	0.0137	8,315	0.3333**
Entries	55	580,759**	0.0342**	271,737**	0.1510**
Parentals	7	866,357**	0.0439**	308,995**	0.1530**
Hybrids	15	382,684*	0.0598**	406,733**	0.1929**
Parental blends	15	424,038*	0.0086*	110,219**	0.1762**
Hybrid blends	15	189,273	0.0297**	228,879**	0.0886**
Homo.[a] vs. hetero.[b]	1	742,018*	0.0008	48,581	0.1087
Parental blends vs. hybrid blends	1	6,430,028**	0.0436	490,700**	0.2364**
Hybrids vs. hybrid blends	1	441,893	0.0029	13,983	0.2943**
Error	55	179,772	0.0040	37,335	0.0322
Coeff. of variation, %		11.63	5.80	9.43	6.57

*Significant at the 5% level of probability

**Significant at the 1% level of probability

[a]Homo. = Homogeneous populations (parentals and hybrids)

[b]Hetero. = Heterogeneous populations (parental blends and hybrid blends)

Table 9. Analyses of variance for grain yield, heads/plant, seeds/head, and 100-seed weight for Environment 6

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Replication	1	237	0.0010	103,457	0.1002*
Entries	55	243,802**	0.0094**	289,101**	0.2172**
Parentals	7	77,617*	0.0329**	407,527**	0.1103**
Hybrids	15	129,789**	0.0064**	367,638**	0.3580**
Parental blends	15	36,034	0.0087**	163,498**	0.0594**
Hybrid blends	15	51,795	0.0037	249,599**	0.2076**
Homo.[a] vs. hetero.[b]	1	15,503	0.0026	413	0.0003
Parental blends vs. hybrid blends	1	5,391,684**	0.0001	919,921**	0.9049**
Hybrids vs. hybrid blends	1	791	0.0001	7,204	0.0053
Error	55	32,291	0.0023	27,939	0.0159
Coeff. of variation, %		6.54	4.42	7.73	6.47

*Significant at the 5% level of probability

**Significant at the 1% level of probability

[a]Homo. = Homogeneous populations (parentals and hybrids)

[b]Hetero. = Heterogeneous populations (parental blends and hybrid blends)

Table 10. Analyses of variance for grain yield, heads/plant, seeds/head and 100-seed weight for Environment 7

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Replications	1	998,109**	0.0026	58,835	0.1317**
Entries	55	309,090**	0.0053*	194,972**	0.1025**
Parentals	7	176,934*	0.0080*	193,483**	0.0825**
Hybrids	15	141,464*	0.0045	219,324**	0.1957**
Parental blends	15	125,570	0.0049	90,332*	0.0363**
Hybrid blends	15	95,208	0.0054	100,342*	0.0750**
Homo.[a] vs. hetero.[b]	1	4,644	0.0032	191	0.0034
Parental blends vs. hybrid blends	1	7,119,558**	0.0036	2,141,832**	0.3178**
Hybrids vs. hybrid blends	1	53,882	0.0017	11,881	0.0009
Error	55	70,253	0.0029	44,627	0.0141
Coeff. of variation, %		7.97	4.97	9.07	5.08

*Significant at the 5% level of probability

**Significant at the 1% level of probability

[a]Homo. = Homogeneous populations (parentals and hybrids)

[b]Hetero. = Heterogeneous populations (parental blends and hybrid blends)

Table 11. Analyses of variance for grain yield, heads/plant, seeds/head, and 100-seed weight for Environment 8

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Replications	1	168,019*	0.0049	632	0.0514*
Entries	55	828,765**	0.0034**	279,487**	0.3606**
Parentals	7	371,986**	0.0111**	148,226*	0.3489**
Hybrids	15	653,277**	0.0013	539,695**	0.4393**
Parental blends	15	202,490**	0.0043**	115,863	0.1409**
Hybrid blends	15	388,319**	0.0016	189,381**	0.2552**
Homo.[a] vs. hetero.[b]	1	36,815	0.0023	200,223	0.0270
Parental blends vs. hybrid blends	1	15,021,438**	0.0000	3,188,010**	2,5720**
Hybrids vs. hybrid blends	1	31,595	0.0005	75,625	0.0657*
Error	55	33,355	0.0015	64,021	0.0119
Coeff. of variation, %		8.61	3.71	10.45	7.76

*Significant at the 5% level of probability

**Significant at the 1% level of probability

[a]Homo. = Homogeneous populations (parentals and hybrids)

[b]Hetero. = Heterogeneous populations (parental blends and hybrid blends)

Table 12. Analyses of variance for grain yield, heads/plant, seeds/head, and 100-seed weight for Environment 9

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Replications	1	1,011,369**	0.0007	87,305	0.3140**
Entries	55	505,042**	0.0047**	287,679**	0.2838**
Parentals	7	183,812	0.0100**	292,370**	0.2804**
Hybrids	15	435,559**	0.0045*	182,079**	0.5208**
Parental blends	15	156,295	0.0060**	114,684**	0.0961**
Hybrid blends	15	153,088	0.0015	183,586**	0.1461**
Homo.[a] vs. hetero.[b]	1	4,796	0.0000	238	0.0041
Parental blends vs. hybrid blends	1	10,707,620**	0.0079	3,038,920**	1.9460**
Hybrids vs. hybrid blends	1	168,510	0.0006	62,438	0.1305
Error	55	115,443	0.0023	46,682	0.0325
Coeff. of variation, %		17.18	4.62	10.97	11.28

*Significant at the 5% level of probability

**Significant at the 1% level of probability

[a]Homo. = Homogeneous populations (parentals and hybrids)

[b]Hetero. = Heterogeneous populations (parental blends and hybrid blends)

either Environment 2 or 9. The stress conditions resulting from the late planting at both environments and the early frost at Environment 9 may have been especially reflected by a lessened variation in yield among the parental populations. The mean square for parentals exceeded the five per cent level of probability for Environments 6 and 7, and was highly significant at each of the other five environments. Yields of the hybrids were significantly or highly significantly different at all environments as indicated by the partitioning of mean squares for hybrids. Differences in yield among the parental blends were significant at two environments and highly significant in three environments, but they were not significant in Environments 2, 6, 7, and 9. Hybrid blends displayed highly significant differences for yield in Environments 1, 3, and 8 but not in the other six environments.

The comparisons for yield of homogeneous versus heterogeneous populations showed a highly significant difference only in Environment 3, and significant differences only for Environments 4 and 5. Highly significant differences for yield were observed in all environments for the comparison of parental blends versus hybrid blends. The yield comparisons of hybrids versus hybrid blends were not significant for any of the environments.

In the analyses for heads/plant the mean squares for entries were highly significant except in Environment 7 where it was only significant and in Environment 2 where it was not significant. Partitioning of the entries sum of squares into the four population types disclosed that the parental populations did not differ significantly in two environments, hybrids were not significantly different in three environments, the parental blends mean square was not significant in four environments, and that differences among hybrid blends were not significant in six environments. In all the other environments either significant or highly significant differences were detected for these comparisons.

The comparisons of homogeneous versus heterogeneous populations and hybrids versus hybrid blends for heads/plant were consistent in that significant differences were not detected in any of the environments. The comparisons of parental blends versus hybrid blends exhibited significant differences only in Environment 3 where a highly significant difference was detected.

The analyses of variance for seeds/head and 100-seed weight showed highly significant differences among entries in all environments. Parentals were significant or highly significant in all instances except 100-seed weight in Environment 1. Highly significant differences among hybrids were obtained for both characters in all environments.

Parental blends were not significantly different in Environments 4 and 8 for seeds/head and in Environment 1 for 100-seed weight but were significantly or highly significantly different in the other environments for both characters.

Differences among hybrid blends were highly significant in all environments for 100-seed weight and either significantly or highly significantly different in all environments except Environment 2 for seeds/head.

For the character seeds/head the comparisons of homogeneous versus heterogeneous populations and hybrids versus hybrid blends exhibited no significant differences. For the same character highly significant differences were observed in all environments for the parental blends versus hybrid blends comparison. The homogeneous versus heterogeneous populations mean square for 100-seed weight was not significant in seven of the environments, although it was highly significant in Environment 3 and significant in Environment 4. For the same character a significant difference between parental blends and hybrid blends was not shown for Environment 3 but a significant difference was observed in Environment 4 and highly significant differences were obtained in all other environments. The comparison of hybrids versus hybrid blends for 100-seed weight was significant in Environment 8 and highly significant in Environment 5, but significant differences were not detected in any of the other environments.

When the mean squares associated with each of the population types were ranked for each environment the values for blends, or heterogeneous populations, generally were of lower magnitude than those for the homogeneous populations. The only exceptions occurred for the character heads/plant where the hybrids had the lowest mean square in three out of nine environments. The comparison of mean squares in this manner serves as one indicator of relative variability among the four types of populations, and other comparisons will be made later in the presentation.

To aid in the evaluation of population performance over all environments, Table 13 presents a summary of the level of significance shown for each mean square of the individual environment analyses (Tables 4 through 12).

Results of the combined analyses of variance for all environments are presented in Table 14. For all characters the mean squares for replications, environments, entries, parentals, hybrids, parental blends, hybrid blends, environments x entries, environments x parentals, environments x hybrids, environments x hybrid blends, and environments x parental blends versus hybrid blends were highly significant.

Mean squares for the comparison of homogeneous with heterogeneous populations exceeded the five per cent level of probability only for the characters yield and 100-seed weight. The hybrids versus hybrid blends mean square exceeded the one per cent level of probability for 100-seed weight but for grain yield only the five per cent level was attained. A significant mean square was observed for heads/plant and highly significant mean squares were obtained for the other three characters for the comparison of parental blends versus hybrid blends.

The mean square for the environments x parental blends

Table 13. Summary of levels of significance from individual environment analyses of variance

Source of variation	Degrees of freedom	Environment								
		1	2	3	4	5	6	7	8	9
Yield:										
Replications	1	NS	*	NS	NS	**	NS	**	*	**
Entries	55	**	**	**	**	**	**	**	**	**
Parentals	7	**	NS	**	**	**	*	*	**	NS
Hybrids	15	**	*	**	**	*	**	*	**	**
Parental blends	15	**	NS	**	*	*	NS	NS	**	NS
Hybrid blends	15	**	NS	**	NS	NS	NS	NS	**	NS
Homo.[a] vs. hetero.[b]	1	NS	NS	**	*	*	NS	NS	NS	NS
Parental blends vs. hybrid blends	1	**	**	**	**	**	**	**	**	**
Hybrids vs. hybrid blends	1	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Significant at the 5% level of probability

**Significant at the 1% level of probability

NS - Not significant at the 5% level of probability

[a]Homo. = Homogeneous populations (parentals and hybrids)

[b]Hetero. = Heterogeneous populations (parental blends and hybrid blends)

Table 13 (Continued)

Source of variation	Degrees of freedom	Environment								
		1	2	3	4	5	6	7	8	9
Heads/plant:										
Replications	1	NS	*	*	**	NS	NS	NS	NS	NS
Entries	55	**	NS	**	**	**	**	*	**	**
Parentals	7	**	NS	NS	**	**	**	*	**	**
Hybrids	15	**	NS	**	**	**	**	NS	NS	*
Parental blends	15	*	NS	NS	NS	*	**	NS	**	**
Hybrid blends	15	*	NS	NS	**	**	NS	NS	NS	NS
Homo.[a] vs. hetero.[b]	1	NS	NS	NS	NS	NS	NS	NS	NS	NS
Parental blends vs. hybrid blends	1	NS	NS	**	NS	NS	NS	NS	NS	NS
Hybrids vs. hybrid blends	1	NS	NS	NS	NS	NS	NS	NS	NS	NS
Seeds/head:										
Replications	1	NS	**	**	NS	NS	NS	NS	NS	NS
Entries	55	**	**	**	**	**	**	**	**	**
Parentals	7	**	**	**	**	**	**	**	*	**
Hybrids	15	**	**	**	**	**	**	**	**	**
Parental blends	15	**	*	**	NS	**	**	*	NS	**
Hybrid blends	15	**	NS	**	*	**	**	*	**	**
Homo.[a] vs. hetero.[b]	1	NS	NS	NS	NS	NS	NS	NS	NS	NS
Parental blends vs. hybrid blends	1	**	**	**	**	**	**	**	**	**
Hybrids vs. hybrid blends	1	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 13 (Continued)

Source of variation	Degrees of freedom	Environment								
		1	2	3	4	5	6	7	8	9
100-seed weight:										
Replications	1	NS	NS	NS	NS	**	*	**	*	**
Entries	55	**	**	**	**	**	**	**	**	**
Parentals	7	NS	**	**	**	**	**	**	**	**
Hybrids	15	**	**	**	**	**	**	**	**	**
Parental blends	15	NS	**	**	**	**	**	**	**	**
Hybrid blends	15	**	**	**	**	**	**	**	**	**
Homo.[a] vs. hetero.[b]	1	NS	NS	**	*	NS	NS	NS	NS	NS
Parental blends vs. hybrid blends	1	**	**	NS	*	**	**	**	**	**
Hybrids vs. hybrid blends	1	NS	NS	NS	NS	**	NS	NS	*	NS

Table 14. Combined analyses of variance for grain yield, heads/plant, seeds/head, and 100-seed weight over nine environments

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Replications	9	590,803**	0.0158**	143,596**	0.1087**
Environments (Env.)	8	40,325,728**	0.3329**	9,754,506**	22.1670**
Entries (Ent.)	55	2,240,198**	0.0451**	1,547,605**	0.9796**
Parentals (Par.)	7	950,378**	0.1099**	1,565,058**	0.5375**
Hybrids (Hy.)	15	853,836**	0.0591**	1,903,235**	1.8012**
Parental blends (PB)	15	287,376**	0.0240**	634,540**	0.2959**
Hybrid blends (HB)	15	464,906**	0.0285**	773,632**	0.8572**
Homo.[a] vs. hetero.[b]	1	343,237*	0.0001	26,971	0.1147*
Parental blends vs. hybrid blends	1	57,176,912**	0.0163*	13,086,306**	4.0384**
Hybrids vs. hybrid blends	1	427,662*	0.0007	84,536	0.2116**

*Significant at the 5% level of probability

**Significant at the 1% level of probability

[a]Homo. = Homogeneous populations (parentals and hybrids)

[b]Hetero. = Heterogeneous populations (parental blends and hybrid blends)

Table 14 (Continued)

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Env. x Ent.	440	202,670**	0.0065**	66,156**	0.0765**
Env. x Par.	56	270,270**	0.0059**	72,025**	0.1410**
Env. x Hy.	120	272,633**	0.0090**	70,087**	0.0721**
Env. x PB	120	154,414**	0.0037	46,335	0.0727**
Env. x HB	120	137,458**	0.0053**	70,411**	0.0371**
Env. x Homo. vs. hetero.	8	164,112*	0.0027	46,499	0.0621**
Env. x PB vs. HB	8	471,478**	0.0233**	161,300**	0.2981**
Env. x Hy. vs. HB	8	71,600	0.0013	18,258	0.0416*
Error	495	75,290	0.0032	40,093	0.0197

interaction exceeded the one per cent level of probability for yield and 100-seed weight but was not significant for heads/plant and seeds/head. Similarly, the interaction of environments with homogeneous versus heterogeneous populations was not significant for heads/plant and seeds/head, but was significant for yield and highly significant for 100-seed weight. However, the interaction of hybrids versus hybrid blends with environments was significant only for 100-seed weight.

The foregoing presentation dealt with the standard analyses of variance necessary to determine if the environments were truly different and if the entries responded differently to these environments. The remainder of this section will deal with the analyses and presentation of data when stability parameters were estimated.

In the review of literature different interpretations or definitions of a stable variety were presented. Therefore, a clarification or statement of concept of a stable variety for this dissertation is necessary. The ideal stable variety is hereby defined as one with a regression coefficient of 1.0, deviations from regression near zero, and a high mean yield.

For the stability analyses to have meaning the environments used must differ significantly and be representative of a full range of possible environmental conditions. The environmental means presented in Table 15 and the variance analyses shown in Tables 13 and 14 indicate that these requirements were met in this investigation. Also presented in Table 15 are the number of environments with means exceeding the mean of all environments, and the range from the highest to the lowest environmental mean. The individual means for each entry at each environment also exhibited a wide range of expression for all characters and are listed for reference in Tables 29 through 32 in the Appendix.

Table 15. Environmental means and ranges of means for yield, heads/plant, seeds/head, and 100-seed weight

Environment	Yield (grams/ plot)	Heads/ plant	Seeds/ head	100-seed weight (grams)
1	3228	1.113	1898	2.592
2	2438	1.007	1907	2.038
3	2304	1.175	1405	2.361
4	2782	1.010	1901	2.387
5	3646	1.097	2049	2.732
6	2746	1.075	2161	1.948
7	3324	1.083	2329	2.343
8	2122	1.029	2421	1.407
9	1977	1.045	1969	1.598
$LSD_{.05}$	73	0.015	53	0.037
All env.	2752	1.070	2004	2.156
Range	1669	0.168	1016	1.325
Number of environments above mean	4	5	4	5

A hybrid was the highest yielding entry in all environments except Environment 9 where the highest yielder was a hybrid blend. The highest mean yield across all environments was exhibited by the hybrid Redlan x Tx 7078; however, it out yielded the second highest entry, the hybrid blend Redlan x Norghum and Kafir 60 x Tx 7078, by only 16 grams/plot. The lowest yielding entry was a parental line (Norghum) and the second lowest entry was a parental blend (Westland and Norghum).

Table 16 gives a presentation of the analyses of variance when stability parameters are estimated following the model described by Eberhart and Russell (1966). The first part of the table is similar to the combined analyses of variance presented previously (Table 14) except for the partitioning of the entries sums of squares. The partitioning differs in that the sums of squares associated with the three degrees of freedom remaining after partitioning the sums of squares for parentals, hybrids, parental blends, and hybrid blends are pooled and designated as the "among groups" component. This partitioning delineates the sum of squares resulting from differences among the four types of populations. For grain yield and seeds/head the four types of populations differed significantly, but significance was not indicated among the groups for 100-seed weight and heads/plant.

The test of genetic differences among entries for their regression upon the environmental indices, i.e., entries x

Table 16. Analyses of variance when stability parameters are estimated

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Reps./environments (Env.)	9	590,803	0.0158	143,596	0.1087
Entries (Ent.)	55	2,240,198**	0.0451**	1,547,605**	0.9796**
Parentals (Par.)	7	950.378**	0.1099**	1,565,058**	0.5375**
Hybrids (Hy.)	15	853,836**	0.0591**	1,903,235**	1.8012**
Parental blends (PB)	15	287,376*	0.0240**	634,540**	0.2959**
Hybrid blends (HB)	15	464,906**	0.0285**	773,632**	0.8572**
Among groups (Amg. gp.)	3	30,822,165**	0.0360	8,163,880**	1.9329
Environments	8	40,325,728	0.3329	9,754,506	22.1670
Ent. x Env.	440	202,670	0.0065	66,156	0.0765
Env. (linear)	1	322,606,346	2.6630	78,035,897	177.3362
Ent. x Env. (lin.)	55	434,065**	0.0149**	81,798	0.3096**
Par. x Env. (lin.)	7	716,918**	0.0068	29,640	0.6491**
Hy. x Env. (lin.)	15	614,140**	0.0242**	151,272**	0.2873**
PB x Env. (lin.)	15	405,079**	0.0060	61,608	0.2720**
HB x Env. (lin.)	15	155,362	0.0069	49,768	0.1148**
Amg. gp. x Env. (lin.)	3	412,151*	0.0712 **	117,233	0.7906**
Pooled deviations	392	166,597	0.0052**	62,782	0.0424**

*Significant at the 5 per cent level of probability

**Significant at the 1 per cent level of probability

Table 16 (Continued)

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Parentals					
Pooled dev. (Par.)	56	199,462**	0.0058**	77,237**	0.0664**
Martin	7	20,037	0.0012	56,704	0.0784**
Kafir 60	7	130,285	0.0060	30,420	0.0491*
Westland	7	70,601	0.0009	130,052**	0.0824**
Redlan	7	273,767**	0.0006	44,446	0.1345**
Tx 7078	7	69,994	0.0054	63,971	0.0260
Caprock	7	231,666**	0.0008	114,565**	0.0281
Plainsman	7	272,425**	0.0114**	134,253**	0.0590**
Norghum	7	526,926**	0.0201**	43,505	0.0742**
Hybrids					
Pooled dev. (Hy.)	112	214,335**	0.0069**	60,888**	0.0411**
Martin x Tx 7078	7	62,085	0.0009	53,280	0.0418*
Martin x Caprock	7	145,386	0.0014	12,891	0.0209
Martin x Plainsman	7	83,716	0.0054	15,628	0.0281
Martin x Norghum	7	383,090**	0.0087**	105,120*	0.0296
Kafir 60 x Tx 7078	7	74,551	0.0032	53,744	0.0294
Kafir 60 x Caprock	7	92,682	0.0006	22,941	0.0191
Kafir 60 x Plainsman	7	44,085	0.0034	29,118	0.0254
Kafir 60 x Norghum	7	494,285**	0.0149**	65,116	0.0553**
Westland x Tx 7078	7	112,526	0.0023	72,559	0.0475*
Westland x Caprock	7	141,393	0.0019	58,663	0.0272
Westland x Plainsman	7	96,669	0.0093**	92,579*	0.0207
Westland x Norghum	7	405,130**	0.0283**	52,216	0.0368
Redlan x Tx 7078	7	300,098**	0.0021	10,223	0.0175
Redlan x Caprock	7	338,369**	0.0017	73,506	0.0885**
Redlan x Plainsman	7	159,670*	0.0047	83,647*	0.0969**
Redlan x Norghum	7	495,620**	0.0214**	172,973**	0.0729**

Table 16 (Continued)

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Parental blends					
Pooled dev. (PB)	112	129,097**	0.0037	49,035	0.0461**
Martin + Tx 7078	7	55,992	0.0010	19,338	0.0126
Martin + Caprock	7	208,047**	0.0018	114,962**	0.0283
Martin + Plainsman	7	334,018**	0.0066*	25,743	0.0660**
Martin + Norghum	7	61,494	0.0079*	15,890	0.0225
Kafir 60 + Tx 7078	7	112,102	0.0026	10,538	0.0255
Kafir 60 + Caprock	7	168,862*	0.0046	67,577	0.0357
Kafir 60 + Plainsman	7	61,476	0.0023	43,202	0.0163
Kafir 60 + Norghum	7	75,011	0.0035	8,464	0.0071
Westland + Tx 7078	7	45,685	0.0025	36,774	0.0133
Westland + Caprock	7	175,160*	0.0017	52,927	0.0316
Westland + Plainsman	7	94,626	0.0055	38,088	0.0248
Westland + Norghum	7	74,422	0.0079*	11,986	0.0560**
Redlan + Tx 7078	7	71,703	0.0020	30,073	0.0956**
Redlan + Caprock	7	191,881*	0.0016	154,945**	0.1276**
Redlan + Plainsman	7	223,347**	0.0014	81,226	0.0645**
Redlan + Norghum	7	111,724	0.0056	72,821	0.1102**
Hybrid blends					
Pooled dev. (HB)	112	139,925**	0.0049**	71,196**	0.0281**
Martin x Norghum + Redlan x Tx 7078	7	245,184**	0.0040	30,979	0.0060
Redlan x Tx 7078 + Westland x Plainsman	7	94,120	0.0028	76,662	0.0222
Westland x Plainsman + Westland x Tx 7078	7	74,538	0.0018	53,032	0.0134

Table 16 (Continued)

Source of variation	Degrees of freedom	Mean square			
		Yield	Heads/plant	Seeds/head	100-seed weight
Westland x Tx 7078 + Westland x Norghum	7	157,163*	0.0021	34,994	0.0356
Westland x Norghum + Kafir 60 x Plainsman	7	194,306*	0.0079*	18,963	0.0326
Kafir 60 x Plainsman + Martin x Tx 7078	7	62,990	0.0025	21,360	0.0227
Martin x Tx 7078 + Westland x Caprock	7	62,644	0.0068*	132,679**	0.0413*
Westland x Caprock + Redlan x Norghum	7	103,017	0.0150**	75,236	0.0387
Redlan x Norghum + Kafir 60 x Tx 7078	7	319,712**	0.0149**	150,993**	0.0440*
Kafir 60 x Tx 7078 + Martin x Caprock	7	101,902	0.0030	15,910	0.0184
Martin x Caprock + Redlan x Plainsman	7	194,742*	0.0016	83,157*	0.0126
Redlan x Plainsman + Kafir 60 x Norghum	7	25,659	0.0055	81,240	0.0269
Kafir 60 x Norghum + Redlan x Caprock	7	98,008	0.0017	149,931**	0.0435*
Redlan x Caprock + Martin x Plainsman	7	212,978**	0.0030	8,606	0.0072
Martin x Plainsman + Kafir 60 x Caprock	7	85,400	0.0016	31,924	0.0223
Kafir 60 x Caprock + Martin x Norghum	7	206,434**	0.0041	173,475**	0.0626**
Error	495	75,290	0.0032	40,093	0.0197

environments (linear), indicated that there were genetic differences at the one per cent level of probability for all characters except seeds/head. The analogous tests for the four different types of populations showed genetic differences within parentals for yield and 100-seed weight, within hybrids for all characters, within parental blends for yield and 100-seed weight, and within hybrid blends for 100-seed weight. When the same test was made for the among groups x environments (linear) component, yield differences were found to be significant at the five per cent level, heads/plant and 100-seed weight were significant at the one per cent level, and the differences among groups for seeds/head were not significant. The remainder of Table 16 presents the analyses for deviations from regression for the individual entries within each of the four population types and the pooled deviations for each population type.

From this type of analysis three stability parameters can be estimated, namely, the regression coefficient, the deviations from regression, and the entry mean. Tables 17 through 20 present the estimates obtained for each of the attributes measured in this investigation.

Mean grain yields for the individual entries across all environments ranged from 2005 to 3554 grams/plot (64.5 to 107.8 bushels/acre), regression coefficients ranged from 0.345 to 1.744 and the deviations from regression ranged from 20,037 to 526,926. Only three entries (Plainsman, Redlan x Norghum, and

Table 17. Stability parameters for grain yield estimated for each entry

Entry	Mean (grams/plot)	Regression coefficient[a]	Deviations from regression[b]
Parentals			
Martin	2588	1.205*	20,037
Kafir 60	2529	1.012	130,285
Westland	2153	0.862	70,601
Redlan	2714	1.451	273,767**
Tx 7078	2352	0.960	69,994
Caprock	2369	1.426	231,666**
Plainsman	2393	0.964	272,425**
Norghum	2005	0.345	526,926**
Hybrids			
Martin x Tx 7078	3088	0.912	62,085
Martin x Caprock	3000	1.143	145,386
Martin x Plainsman	2781	1.010	83,716
Martin x Norghum	2897	0.307*	383,090**
Kafir 60 x Tx 7078	3258	0.857	74,551
Kafir 60 x Caprock	3151	1.077	92,682
Kafir 60 x Plainsman	2889	0.994	44,085
Kafir 60 x Norghum	3021	0.519	494,285**
Westland x Tx 7078	2779	1.064	112,526
Westland x Caprock	2805	0.942	141,383
Westland x Plainsman	2520	0.953	96,669
Westland x Norghum	3002	0.436	405,130**
Redlan x Tx 7078	3354	1.160	300,098**
Redlan x Caprock	2999	1.694*	338,369**
Redlan x Plainsman	2924	1.126	159,670*
Redlan x Norghum	3313	0.780	495,620**
Parental blends			
Martin + Tx 7078	2400	1.096	55,992
Martin + Caprock	2574	1.222	208,047**
Martin + Plainsman	2368	0.793	334,018**
Martin + Norghum	2324	0.695*	61,494

[a] *Significantly different from 1.0 at the 5 per cent level of prob.
**Significantly different from 1.0 at the 1 per cent level of prob.

[b] *Significantly different from zero at the 5 per cent level of prob.
**Significantly different from zero at the 1 per cent level of prob.

Table 17 (Continued)

Entry	Mean (grams/plot)	Regression coefficient[a]	Deviations from regression[b]
Kafir 60 + Tx 7078	2367	1.083	112,102
Kafir 60 + Caprock	2455	0.988	168,862*
Kafir 60 + Plainsman	2361	1.009	61,476
Kafir 60 + Norghum	2419	0.720*	75,011
Westland + Tx 7078	2329	0.977	45,685
Westland + Caprock	2441	1.264	175,160*
Westland + Plainsman	2557	1.083	94,626
Westland + Norghum	2109	0.889	74,422
Redlan + Tx 7078	2511	1.156	71,703
Redlan + Caprock	2499	1.744**	191,881*
Redlan + Plainsman	2591	1.373	223,347**
Redlan + Norghum	2567	1.299	111.724
<u>Hybrid blends</u>			
Martin x Norghum + Redlan x Tx 7078	3114	0.778	245,184**
Redlan x Tx 7078 + Westland x Plainsman	2987	0.948	94,120
Westland x Plainsman + Westland x Tx 7078	2648	0.888	74,538
Westland x Tx 7078 + Westland x Norghum	3020	0.846	157,163*
Westland x Norghum + Kafir 60 x Plainsman	2997	0.901	194,306*
Kafir 60 x Plainsman + Martin x Tx 7078	3008	0.937	662,990
Martin x Tx 7078 + Westland x Caprock	2875	0.932	62,644
Westland x Caprock + Redlan x Norghum	3146	0.911	103,017
Redlan x Norghum + Kafir 60 x Tx 7078	3338	0.729	319,712**
Kafir 60 x Tx 7078 + Martin x Caprock	3207	1.179	101,902
Martin x Caprock + Redlan x Plainsman	2929	1.213	194,742*
Redlan x Plainsman + Kafir 60 x Norghum	3088	0.990	25,659
Kafir 60 x Norghum + Redlan x Caprock	3262	1.258	98,008

Table 17 (Continued)

Entry	Mean (grams/plot)	Regression coefficient[a]	Deviations from regression[b]
Redlan x Caprock + Martin x Plainsman	2997	1.191	212,978**
Martin x Plainsman + Kafir 60 x Caprock	3000	0.941	85,400
Kafir 60 x Caprock + Martin x Norghum	3037	0.767	206,434**
$LSD_{.05}$	181		

Table 18. Stability parameters for number of heads/plant for each entry

Entry	Mean	Regression coefficient[a]	Deviations from regression[b]
Parentals			
Martin	1.032	0.470*	0.0012
Kafir 60	1.043	0.584	0.0060
Westland	1.015	0.194**	0.0009
Redlan	1.022	0.181**	0.0006
Tx 7078	1.044	0.564	0.0054
Caprock	1.024	0.913	0.0008
Plainsman	1.074	1.096	0.0114**
Norghum	1.251	1.163	0.0201**
Hybrids			
Martin x Tx 7078	1.053	0.766	0.0009
Martin x Caprock	1.048	0.840	0.0014
Martin x Plainsman	1.066	1.245	0.0054
Martin x Norghum	1.166	2.195*	0.0087**
Kafir 60 x Tx 7078	1.072	1.393	0.0032
Kafir 60 x Caprock	1.029	0.299**	0.0006
Kafir 60 x Plainsman	1.039	0.759	0.0034
Kafir 60 x Norghum	1.145	2.030	0.0149**
Westland x Tx 7078	1.057	0.787	0.0023
Westland x Caprock	1.041	0.400*	0.0018
Westland x Plainsman	1.046	1.712	0.0093**
Westland x Norghum	1.198	2.916*	0.0283**
Redlan x Tx 7078	1.055	0.917	0.0021
Redlan x Caprock	1.031	0.960	0.0017
Redlan x Plainsman	1.016	0.679	0.0047
Redlan x Norghum	1.165	1.615	0.0214**
Parental blends			
Martin + Tx 7078	1.071	1.101	0.0010
Martin + Caprock	1.047	0.632	0.0018
Martin + Plainsman	1.059	0.822	0.0066*
Martin + Norghum	1.123	0.399	0.0079*

[a]*Significantly different from 1.0 at the 5 per cent level of prob.
**Significantly different from 1.0 at the 1 per cent level of prob.

[b]*Significantly different from zero at the 5 per cent level of prob.
**Significantly different from zero at the 1 per cent level of prob.

Table 18 (Continued)

Entry	Mean	Regression coefficient[a]	Deviations from regression[b]
Kafir 60 + Tx 7078	1.042	0.372*	0.0026
Kafir 60 + Caprock	1.042	0.429	0.0046
Kafir 60 + Plainsman	1.039	0.552	0.0023
Kafir 60 + Norghum	1.129	1.052	0.0035
Westland + Tx 7078	1.046	0.295*	0.0025
Westland + Caprock	1.030	0.407*	0.0017
Westland + Plainsman	1.048	0.361	0.0055
Westland + Norghum	1.122	1.112	0.0079*
Redlan + Tx 7078	1.045	0.730	0.0020
Redlan + Caprock	1.027	0.506*	0.0016
Redlan + Plainsman	1.035	0.688	0.0014
Redlan + Norghum	1.116	1.557	0.0056
Hybrid blends			
Martin x Norghum + Redlan x Tx 7078	1.087	1.776*	0.0040
Redlan x Tx 7078 + Westland x Plainsman	1.056	0.943	0.0028
Westland x Plainsman + Westland x Tx 7078	1.021	1.007	0.0018
Westland x Tx 7078 + Westland x Norghum	1.106	1.498	0.0021
Westland x Norghum + Kafir 60 x Plainsman	1.118	1.305	0.0079*
Kafir 60 x Plainsman + Martin x Tx 7078	1.045	0.839	0.0025
Martin x Tx 7078 + Westland x Caprock	1.042	1.181	0.0068*
Westland x Caprock + Redlan x Norghum	1.150	1.786	0.0150**
Redlan x Norghum + Kafir 60 x Tx 7078	1.137	1.211	0.0149**
Kafir 60 x Tx 7078 + Martin x Caprock	1.028	0.778	0.0030
Martin x Caprock + Redlan x Plainsman	1.047	1.004	0.0016
Redlan x Plainsman + Kafir 60 x Norghum	1.077	1.548	0.0055

Table 18 (Continued)

Entry	Mean	Regression coefficient[a]	Deviations from regression[b]
Kafir 60 x Norghum + Redlan x Caprock	1.088	1.662**	0.0017
Redlan x Caprock + Martin x Plainsman	1.046	0.660	0.0030
Martin x Plainsman + Kafir 60 x Caprock	1.041	1.296	0.0016
Kafir 60 x Caprock + Martin x Norghum	1.106	1.821	0.0041
$LSD_{.05}$	0.037		

Table 19. Stability parameters for number of seeds/head for each entry

Entry	Mean	Regression coefficient[a]	Deviations from regression[b]
Parentals			
Martin	2004	0.832	56,704
Kafir 60	1828	1.099	30,402
Westland	1629	1.194	130,052**
Redlan	1874	0.917	44,446
Tx 7078	1859	0.947	63,971
Caprock	2106	0.984	114,565**
Plainsman	2082	1.227	134,253**
Norghum	1201	0.889	43,505
Hybrids			
Martin x Tx 7078	2228	0.834	53,280
Martin x Caprock	2335	0.818	12,891
Martin x Plainsman	2282	1.060	15,628
Martin x Norghum	1560	0.726	105,120*
Kafir 60 x Tx 7078	2135	0.834	53,744
Kafir 60 x Caprock	2201	0.854	22,941
Kafir 60 x Plainsman	2088	0.969	29,118
Kafir 60 x Norghum	1696	0.880	65,116
Westland x Tx 7078	2237	1.069	72,559
Westland x Caprock	2317	1.540*	58,663
Westland x Plainsman	2341	0.929	92,579*
Westland x Norghum	1632	0.941	52,216
Redlan x Tx 7078	2494	0.658**	10,223
Redlan x Caprock	2443	1.233	73,506
Redlan x Plainsman	2670	1.946**	83,647*
Redlan x Norghum	1759	1.269	172,973**
Parental blends			
Martin + Tx 7078	1961	0.674*	19,338
Martin + Caprock	2061	0.876	114,962**
Martin + Plainsman	1907	0.670*	25,743**
Martin + Norghum	1576	0.662*	15,890

[a]*Significantly different from 1.0 at the 5 per cent level of prob.
**Significantly different from 1.0 at the 1 per cent level of prob.

[b]*Significantly different from zero at the 5 per cent level of prob.
**Significantly different from zero at the 1 per cent level of prob.

Table 19 (Continued)

Entry	Mean	Regression coefficient[a]	Deviations from regression[b]
Kafir 60 + Tx 7078	1845	0.892	10,538
Kafir 60 + Caprock	1949	0.749	67,577
Kafir 60 + Plainsman	1982	1.206	43,202
Kafir 60 + Norghum	1583	0.922	8,464
Westland + Tx 7078	1771	0.905	36,774
Westland + Caprock	2022	0.598	52,927
Westland + Plainsman	1888	1.012	38,088
Westland + Norghum	1413	0.905	11,986
Redlan + Tx 7078	1894	1.284	30,073
Redlan + Caprock	1877	1.262	154,945**
Redlan + Plainsman	1898	0.858	81,226
Redlan + Norghum	1583	0.873	72,821
Hybrid blends			
Martin x Norghum + Redlan x Tx 7078	1972	1.048	30,979
Redlan x Tx 7078 + Westland x Plainsman	2380	1.185	76,662
Westland x Plainsman + Westland x Tx 7078	2232	1.119	53,032
Westland x Tx 7078 + Westland x Norghum	1931	0.918	34,994
Westland x Norghum + Kafir 60 x Plainsman	1788	0.797	18,963
Kafir 60 x Plainsman + Martin x Tx 7078	2174	1.041	21,360
Martin x Tx 7078 + Westland x Caprock	2341	1.226	132,679**
Westland x Caprock + Redlan x Norghum	1879	0.979	75,236
Redlan x Norghum + Kafir 60 x Tx 7078	1908	1.166	150,993**
Kafir 60 x Tx 7078 + Martin x Caprock	2286	0.888	15,910
Martin x Caprock + Redlan x Plainsman	2424	1.317	83,157*
Redlan x Plainsman + Kafir 60 x Norghum	2129	0.890	81,240

Table 19 (Continued)

Entry	Mean	Regression coefficient[a]	Deviations from regression[b]
Kafir 60 x Norghum + Redlan x Caprock	2051	0.898	149,931**
Redlan x Caprock + Martin x Plainsman	2328	0.909	8,606
Martin x Plainsman + Kafir 60 x Caprock	2298	1.096	31,924
Kafir 60 x Caprock + Martin x Norghum	1912	1.514	173,475**
$LSD_{.05}$	132		

Table 20. Stability parameters for 100-seed weight estimated for each entry

Entry	Mean (grams)	Regression coefficient[a]	Deviations from regression[b]
Parentals			
Martin	2.026	1.039	0.0784**
Kafir 60	2.158	1.292	0.0491*
Westland	2.123	0.973	0.0824**
Redlan	2.306	1.690*	0.1345**
Tx 7078	2.042	1.008	0.0260
Caprock	1.806	1.490**	0.0281
Plainsman	1.851	1.006	0.0590**
Norghum	2.219	0.171**	0.0742**
Hybrids			
Martin x Tx 7078	2.153	0.728*	0.0418*
Martin x Caprock	2.013	1.119	0.0209
Martin x Plainsman	1.910	0.904	0.0281
Martin x Norghum	2.676	0.429**	0.0296
Kafir 60 x Tx 7078	2.346	0.833	0.0294
Kafir 60 x Caprock	2.307	1.201*	0.0191
Kafir 60 x Plainsman	2.151	1.054	0.0254
Kafir 60 x Norghum	2.678	0.470**	0.0553**
Westland x Tx 7078	1.918	0.872	0.0475*
Westland x Caprock	1.982	1.012	0.0272
Westland x Plainsman	1.743	0.792*	0.0207
Westland x Norghum	2.586	0.530**	0.0368
Redlan x Tx 7078	2.110	1.092	0.0175
Redlan x Caprock	2.008	1.585*	0.0885**
Redlan x Plainsman	1.916	1.082	0.0969**
Redlan x Norghum	2.728	0.662	0.0729**
Parental blends			
Martin + Tx 7078	1.993	1.067	0.0126
Martin + Caprock	1.958	1.126	0.0283
Martin + Plainsman	1.930	0.927	0.0660**
Martin + Norghum	2.141	0.704**	0.0225

[a]*Significantly different from 1.0 at the 5 per cent level of P
**Significantly different from 1.0 at the 1 per cent level of P

[b]*Significantly different from zero at the 5 per cent level of P
**Significantly different from zero at the 1 per cent level of P

Table 20 (Continued)

Entry	Mean (grams)	Regression coefficient[a]	Deviations from regression[b]
Parental blends (continued)			
Kafir 60 + Tx 7078	2.040	1.160	0.0255
Kafir 60 + Caprock	1.986	1.193	0.0357
Kafir 60 + Plainsman	1.943	1.032	0.0163
Kafir 60 + Norghum	2.199	0.735**	0.0071
Westland + Tx 7078	2.052	1.067	0.0133
Westland + Caprock	1.919	1.267*	0.0316
Westland + Plainsman	1.973	1.211*	0.0248
Westland + Norghum	2.216	0.859	0.0560**
Redlan + Tx 7078	2.176	1.413*	0.0956**
Redlan + Caprock	2.094	1.770**	0.1276**
Redlan + Plainsman	2.176	1.665**	0.0645**
Redlan + Norghum	2.364	1.282	0.1102**
Hybrid blends			
Martin x Norghum + Redlan x Tx 7078	2.406	0.692**	0.0060
Redlan x Tx 7078 + Westland x Plainsman	2.087	1.108	0.0222
Westland x Plainsman + Westland x Tx 7078	1.838	0.810*	0.0134
Westland x Tx 7078 + Westland x Norghum	2.296	0.662*	0.0356
Westland x Norghum + Kafir 60 x Plainsman	2.426	0.679*	0.0326
Kafir 60 x Plainsman + Martin x Tx 7078	2.161	0.891	0.0227
Martin x Tx 7078 + Westland x Caprock	1.972	1.000	0.0413*
Westland x Caprock + Redlan x Norghum	2.494	0.987	0.0387
Redlan x Norghum + Kafir 60 x Tx 7078	2.577	0.741	0.0440*
Kafir 60 x Tx 7078 + Martin x Caprock	2.164	0.996	0.0184
Martin x Caprock + Redlan x Plainsman	2.007	1.099	0.0126
Redlan x Plainsman + Kafir 60 x Norghum	2.347	0.656**	0.0269

Table 20(Continued)

Entry	Mean (grams)	Regression coefficient[a]	Deviations from regression[b]
Hybrid blends (continued)			
Kafir 60 x Norghum + Redlan x Caprock	2.428	0.844	0.0435*
Redlan x Caprock + Martin x Plainsman	2.064	1.306**	0.0072
Martin x Plainsman + Kafir 60 x Caprock	2.104	1.019	0.0223
Kafir 60 x Caprock + Martin x Norghum	2.468	1.003	0.0626**
$LSD_{.05}$	0.093		

Martin and Plainsman) had significant deviations from regression for all characters and 19 entries had deviations that were not significant for any of the characters. For grain yield, three regression coefficients were significantly greater than 1.0, and three were significantly less than 1.0. The character heads/plant exhibited four regression coefficients significantly greater than 1.0 and nine were significantly less than 1.0. Only two regression coefficients were significantly greater than 1.0 and four significantly less than 1.0 for seeds/head, whereas 100-seed weight showed 10 coefficients significantly greater than and 13 significantly less than 1.0. Thus most entries did not exhibit coefficients that were significantly different from the average regression (b=1.0) upon the environmental indices.

A primary objective of the experiment was to evaluate both the relative productivity and stability of performance of the four types of populations over a series of environments. For this purpose the stability parameters for each population type are presented in Table 21. Interpretation of the regression coefficients for the different populations should be tempered by the fact that the procedure for calculating the environmental indices leads to an average regression coefficient of 1.0, and the compositing of individual entries may result in group regression coefficients that tend to approach the average.

Table 21. Stability parameters estimated for yield, heads/plant, seeds/head, and 100-seed weight of four types of grain sorghum populations

Population and character	Mean	Regression coefficient[a]	Deviations from regression[b]
Yield (grams/plot):			
Parentals	2388	1.628	199,462**
Hybrids	2985	0.936	214,335**
Parental blends	2411	1.087*	129,097**
Hybrid blends	3041	0.963	139,925**
$LSD_{.05}$[c]	55		
$LSD_{.05}$[d]	45		
Heads/plant:			
Parentals	1.063	0.646**	0.0058**
Hybrids	1.077	1.220*	0.0069**
Parental blends	1.064	0.688	0.0037
Hybrid blends	1.075	1.270**	0.0049**
$LSD_{.05}$[c]	0.011		
$LSD_{.05}$[d]	0.009		

[a]*Significantly different from 1.0 at the 5% level of P.
**Significantly different from 1.0 at the 1% level of P.

[b]*Significantly different from zero at the 5% level of P.
**Significantly different from zero at the 1% level of P.

[c]LSD to be used when comparing parentals with hybrids, parental blends or hybrid blends.

[d]LSD to be used when comparing hybrids, parental blends or hybrid blends with each other.

Table 21 (Continued)

Population and character	Mean	Regression coefficient[a]	Deviations from regression[b]
Seeds/head:			
Parentals	1823	1.011	77,237**
Hybrids	2151	1.035	60,888**
Parental blends	1828	0.897*	49,035
Hybrid blends	2127	1.062	71,196**
$LSD_{.05}$[c]	40		
$LSD_{.05}$[d]	33		
100-seed weight (grams):			
Parentals	2.066	1.084	0.0664**
Hybrids	2.202	0.898**	0.0664**
Parental blends	2.073	1.155**	0.0461**
Hybrid blends	2.240	0.906**	0.0281**
$LSD_{.05}$[c]	0.028		
$LSD_{.05}$[d]	0.023		

For yield the hybrid blends had the highest mean and a regression coefficient not different from unity, although deviations from regression were different from zero at the one per cent level of probability. The single degree of freedom comparisons given in Table 14 indicated that hybrid blends yielded significantly more than either the hybrids or parental blends. The same relative performance was observed for these populations for 100-seed weight, but the data for heads/plant and seeds/head deviated somewhat from this pattern. For all characters the heterogeneous populations tended to be slightly superior to the comparable homogeneous populations for all stability parameters.

Tables 22 through 25 list the environmental means for all characters for the four types of populations. In addition, the data are categorized further into two groups, homogeneous (non-blended) populations and heterogeneous (blended) populations. Ratios expressed in percentage also are listed in each table for comparing the relative performance of heterogeneous and homogeneous populations. The ratios would be expected to equal 100 per cent if the blended populations exhibited no advantage or disadvantage in comparisons with the homogeneous types.

The expected yields of the blends can be computed by taking a weighted mean of the yields in pure stands for the components contained in the blend. The expected mean yields,

Table 22. Mean yield in grams/plot for each population type and environment

Environ-ment	Parentals	Hybrids	Parental blends	Hybrid blends	$LSD_{.05}$[a]	$LSD_{.05}$[b]	Homo.[c]	Hetero.[d]	Hetero./homo.(%)
1	3157	3597	3173	3649	149	122	3377	3411	101.0
2	2221	2654	2173	2594	165	135	2438	2384	97.8
3	1811	2508	2032	2620	169	138	2159	2326	107.7
4	2421	3011	2500	3017	123	100	2716	2758	101.6
5	3182	3824	3356	3990	260	212	3503	3673	104.9
6	2380	2996	2422	3003	110	90	2688	2713	100.9
7	3032	3556	2947	3614	163	133	3294	3281	99.6
8	1684	2378	1564	2533	112	91	2031	2048	100.9
9	1604	2344	1528	2346	208	170	1974	1937	98.2
All Env.	2388	2985	2411	3041	55	45	2687	2726	101.5

[a] LSD to be used when comparing parentals with hybrids, parental blends or hybrid blends

[b] LSD to be used when comparing hybrids, parental blends or hybrid blends with each other

[c] Homo. = Homogeneous populations (parentals and hybrids)

[d] Hetero. = Heterogeneous populations (parental blends and hybrid blends)

Table 23. Mean number of heads/plant for each population type and environment

Environ-ment	Parentals	Hybrids	Parental blends	Hybrid blends	$LSD_{.05}$[a]	$LSD_{.05}$[b]	Homo.[c]	Hetero.[d]	Hetero./homo. (%)
1	1.111	1.109	1.109	1.122	NS	NS	1.110	1.116	100.5
2	1.012	1.008	1.010	1.001	NS	NS	1.010	1.006	99.6
3	1.110	1.221	1.122	1.215	0.057	0.046	1.166	1.169	100.3
4	1.005	1.010	1.020	1.002	NS	NS	1.008	1.011	100.3
5	1.061	1.129	1.063	1.116	0.039	0.032	1.095	1.090	99.5
6	1.094	1.071	1.072	1.074	NS	NS	1.083	1.073	99.1
7	1.084	1.071	1.096	1.082	NS	NS	1.078	1.089	101.0
8	1.039	1.031	1.025	1.025	NS	NS	1.035	1.025	99.0
9	1.052	1.040	1.056	1.034	NS	NS	1.046	1.045	100.0
All Env.	1.063	1.077	1.064	1.075	0.011	0.009	1.070	1.070	100.0

[a]LSD to be used when comparing parentals with hybrids, parental blends or hybrid blends

[b]LSD to be used when comparing hybrids, parental blends or hybrids with each other

[c]Homo. = Homogeneous populations (parentals and hybrids)

[d]Hetero. = Heterogeneous populations (parental blends and hybrid blends)

Table 24. Mean number of seeds/head for each population type and environment

Environ- ment	Parentals	Hybrids	Parental blends	Hybrid blends	$LSD_{.05}$[a]	$LSD_{.05}$[b]	Homo.[c]	Hetero.[d]	Hetero./ homo. (%)
1	1794	2007	1768	1972	52	92	1900	1870	98.4
2	1743	2033	1747	2023	135	110	1888	1885	99.8
3	1227	1542	1269	1495	100	81	1384	1382	99.8
4	1700	2058	1700	2045	110	89	1879	1873	99.6
5	1840	2161	1957	2132	119	97	2001	2044	102.2
6	2055	2245	2026	2266	103	84	2150	2146	99.8
7	2155	2461	2123	2488	130	106	2308	2306	99.9
8	2239	2646	2131	2577	155	127	2442	2354	96.4
9	1654	2208	1710	2146	133	108	1931	1928	99.8
All Env.	1823	2151	1826	2127	40	33	1987	1976	99.5

[a] LSD to be used when comparing parentals with hybrids, parental blends or hybrid blends

[b] LSD to be used when comparing hybrids, parental blends or hybrids with each other

[c] Homo. = Homogeneous populations (parentals and hybrids)

[d] Hetero. = Heterogeneous populations (parental blends and hybrid blends)

Table 25. Mean 100-seed weight in grams for each population type and environment

Environ-ment	Parentals	Hybrids	Parental blends	Hybrid blends	$LSD_{.05}$[a]	$LSD_{.05}$[b]	Homo.[c]	Hetero.[d]	Hetero./homo. (%)
1	2.501	2.632	2.530	2.661	0.099	0.081	2.567	2.596	101.1
2	2.026	2.085	1.971	2.064	0.071	0.058	2.056	2.018	98.1
3	2.236	2.358	2.400	2.387	0.096	0.078	2.297	2.394	104.2
4	2.332	2.392	2.376	2.421	0.048	0.039	2.362	2.399	101.6
5	2.706	2.687	2.701	2.822	0.110	0.090	2.697	2.762	102.4
6	1.785	2.066	1.810	2.048	0.077	0.063	1.926	1.929	100.2
7	2.291	2.394	2.261	2.402	0.073	0.060	2.343	2.332	99.5
8	1.195	1.533	1.196	1.597	0.067	0.058	1.364	1.397	102.4
9	1.524	1.667	1.408	1.757	0.111	0.090	1.596	1.583	99.2
All Env.	2.066	2.202	2.073	2.240	0.028	0.023	2.134	2.157	101.1

[a]LSD to be used when comparing parentals with hybrids, parental blends or hybrid blends

[b]LSD to be used when comparing hybrids, parental blends or hybrids with each other

[c]Homo. = Homogeneous populations (parentals and hybrids)

[d]Hetero. = Heterogeneous populations (parental blends and hybrid blends)

the observed mean yields, and their ratios in percentages are presented as means for all environments in Table 26. The expected mean was calculated with the assumption that the blend was comprised of a 1:1 ratio of the two components, although as described previously, this proportion was not verified for all final stands. Differences between expected and observed yields of the blends were not tested for significance. The pooled error term was not deemed appropriate for use in calculating an LSD for this comparison and there did not appear to be a valid test of significance on an individual entry basis. For the data from individual environments the ratios of observed to expected yields ranged from 61 to 124 per cent, whereas means of the ratios over all nine environments ranged from 95 to 112 per cent. Twenty-two of the 32 blends exhibited yields that were superior to the mean of the components.

Comparisons for the performance of the blends relative to the higher yielding component of each mixture are given in Table 27. Again tests for significance were not made of the differences between the higher yielding component and the observed yield of the blend. For the individual environment data the range for yields of blends expressed as a percentage of the higher yielding component was from 61 to 117 per cent. When the yields were averaged over all environments the range was from 89 to 108 per cent. Five of the 32 blends had mean yields that exceeded the more productive component of the blend.

Table 26. Observed and expected mean yields of blends averaged over all environments and observed yield expressed as a percentage of the expected mean yield

Entry	Expected yield[a] (grams/plot)	Observed yield (grams/plot)	Observed/ Expected yield (%)
Parental blends			
Martin + Tx 7078	2470	2400	97.2
Martin + Caprock	2479	2574	103.9
Martin + Plainsman	2491	2368	95.1
Martin + Norghum	2297	2324	101.2
Kafir 60 + Tx 7078	2441	2367	97.0
Kafir 60 + Caprock	2449	2455	100.2
Kafir 60 + Plainsman	2461	2361	95.9
Kafir 60 + Norghum	2267	2419	106.7
Westland + Tx 7078	2253	2329	103.4
Westland + Caprock	2261	2441	108.0
Westland + Plainsman	2273	2557	112.5
Westland + Norghum	2079	2109	101.5
Redlan + Tx 7078	2533	2511	99.1
Redlan + Caprock	2542	2499	98.3
Redlan + Plainsman	2554	2591	101.5
Redlan + Norghum	2360	2567	108.8
Hybrid blends			
Martin x Norghum + Redlan x Tx 7078	3125	3114	99.7
Redlan x Tx 7078 + Westland x Plainsman	2937	2987	101.7
Westland x Plainsman + Westland x Tx 7078	2650	2648	99.9
Westland x Tx 7078 + Westland x Norghum	2891	3020	104.5
Westland x Norghum + Kafir 60 x Plainsman	2946	2997	101.8
Kafir 60 x Plainsman + Martin x Tx 7078	2988	3008	100.7
Martin x Tx 7078 + Westland x Caprock	2947	2875	97.6

[a]Expected yield = mean yield of components grown in pure stands

Table 26 (Continued)

Entry	Expected yield[a] (grams/plot)	Observed yield (grams/plot)	Observed/ Expected yield (%)
Westland x Caprock + Redlan x Norghum	3059	3146	102.9
Redlan x Norghum + Kafir 60 x Tx 7078	3286	3338	101.6
Kafir 60 x Tx 7078 + Martin x Caprock	3129	3207	102.5
Martin x Caprock + Redlan x Plainsman	2962	2929	98.9
Redlan x Plainsman + Kafir 60 x Norghum	2973	3088	103.9
Kafir 60 x Norghum + Redlan x Caprock	3010	3262	108.4
Redlan x Caprock + Martin x Plainsman	2890	2997	103.7
Martin x Plainsman + Kafir 60 x Caprock	2966	3000	101.2
Kafir 60 x Caprock + Martin x Norghum	3024	3037	100.4

Table 27. Mean yields of blends and their higher yielding component lines observed over all environments

Entry	Yield of high[a] component (grams/plot)	Yield of blend (grams/plot)	Yield of blend as % of high component
Parental blends			
Martin + Tx 7078	2588	2400	92.7
Martin + Caprock	2588	2574	99.5
Martin + Plainsman	2588	2368	91.5
Martin + Norghum	2588	2324	89.8
Kafir 60 + Tx 7078	2529	2367	93.6
Kafir 60 + Caprock	2529	2455	97.1
Kafir 60 + Plainsman	2529	2361	93.4
Kafir 60 + Norghum	2529	2419	95.7
Westland + Tx 7078	2352	2329	99.0
Westland + Caprock	2369	2441	103.0
Westland + Plainsman	2393	2557	106.8
Westland + Norghum	2153	2109	98.0
Redlan + Tx 7078	2714	2511	92.5
Redlan + Caprock	2714	2499	92.1
Redlan + Plainsman	2714	2591	95.5
Redlan + Norghum	2714	2567	94.6
Hybrid blends			
Martin x Norghum + Redlan x Tx 7078	3354	3114	92.9
Redlan x Tx 7078 + Westland x Plainsman	3354	2987	89.1
Westland + Plainsman + Westland x Tx 7078	2779	2648	95.3
Westland x Tx 7078 + Westland x Norghum	3002	3020	100.6
Westland x Norghum + Kafir 60 x Plainsman	3002	2997	99.8
Kafir 60 x Plainsman + Martin x Tx 7078	3088	3008	97.4
Martin x Tx 7078 + Westland x Caprock	3088	2875	93.1
Westland x Caprock + Redlan x Norghum	3313	3146	95.0
Redlan x Norghum + Kafir 60 x Tx 7078	3313	3338	100.8

[a]Yield of high component in pure stands

Table 27 (Continued)

Entry	Yield of high[a] component (grams/plot)	Yield of blend (grams/plot)	Yield of blend as % of high component
Kafir 60 x Tx 7078 + Martin x Caprock	3258	3207	98.4
Martin x Caprock + Redlan x Plainsman	3000	2929	97.6
Redlan x Plainsman + Kafir 60 x Norghum	3021	3088	102.2
Kafir 60 x Norghum + Redlan x Caprock	3021	3262	108.0
Redlan x Caprock + Martin x Plainsman	2999	2997	99.9
Martin x Plainsman + Kafir 60 x Caprock	3151	3000	95.2
Kafir 60 x Caprock + Martin x Norghum	3151	3037	96.4

The correlations of stability parameters predicted from the performance of components of the hybrid and blended populations with those determined from the mean yields over all environments of the hybrids and blends are presented in Table 28. A nonsignificant negative correlation was shown for deviations from regression for the parental blends, all other correlations were positive. The coefficients for mean yields of the hybrids and deviations from regression for the hybrid blends were relatively low and nonsignificant. All other correlations were of medium or high magnitude and were significant at either the five or one per cent probability level.

Table 28. Correlation coefficients between stability parameters predicted from performance of the components of hybrid and blended populations and those determined from mean yields over all environments of the hybrids and blends

Population	Degrees of freedom	Stability parameter and correlation coefficient		
		Mean yield	Regression coefficient	Deviations from regression
Hybrids	14	0.374	0.890**	0.831**
Parental blends	14	0.594*	0.723**	-0.035
Hybrid blends	14	0.881**	0.787**	0.310

*Significantly different from zero at the five per cent level of probability

**Significantly different from zero at the one per cent level of probability

DISCUSSION

Results presented for the individual environment analyses established that the populations evaluated in this experiment differed in genetic complement and that they varied in their response to the different environmental conditions. The genotypes selected encompassed a wide range of maturity and differed appreciably for height and other plant characteristics. The significant interactions of each population type with environments, shown for most characters in the combined analyses of variance, further substantiates the diversity of genotype and environmental responses encountered. One also might expect significant interactions of environments with the three paired population comparisons. For homogeneous versus heterogeneous populations and for parental blends versus hybrid blends the interactions with environments for grain yield were significant, but the hybrids versus hybrid blends component did not interact significantly with environments. The hybrid blends usually were higher yielding than the hybrids and were never significantly inferior over all environments, thus the response of the two population types to the different environments was sufficiently alike to preclude a significant environment x hybrids versus hybrid blends interaction.

Environment 5 had the highest error mean square for yield among the 1966 experiments and Environment 9 exhibited the highest error term in 1967, yet Environment 9 showed the lowest and Environment 5 the highest mean yield. Generally, the environments that exhibited relatively low variability had average yields that were near the mean for all environments. Thus it appears that the variability expressed at a given environment was not associated with the magnitude of the mean yield.

Analyses of the data when stability parameters were estimated clearly showed that there were differences among the four types of populations for grain yield and seeds/head. For both of these characters, the hybrids and hybrid blends exhibited distinctly higher means than the parental and parental blends (Table 21). The same comparative performance of the populations also was shown by the means for 100-seed weight and heads/plant but the differences were not significant (Table 16). Regression coefficients for grain yield were closer to 1.0 for the hybrid blends and the parental blends than they were for the other populations, and smallest deviations from regression for yield were shown for the two blended populations. For seeds/head regression coefficients were nearest to 1.0 for the parental lines and the hybrids, while deviations from regression were smallest for the parental blends and the hybrids. Thus, while there were distinct differences for population performance as measured by the three stability parameters the patterns of response varied considerably among populations. In general, the hybrids and hybrid blends tended to react in a somewhat more similar manner than did the parentals and parental blends.

The procedures followed in analysis of the data permit the identification of certain entries as being particularly well adapted to some environments and unadapted to others. The parental entry Norghum appears to be unadapted to most of the environments of this experiment as exemplified by its low mean yield over all environments, its low regression coefficient, and its high deviations from regression. In contrast, it was the highest yielding parental entry at Environments 8 and 9. The relative performance of entries at these two environments, however, may have been somewhat atypical because of the abnormally short period between planting and the first frost. Thus, Norghum appears to be delineated as a variety which is specifically adapted to unfavorable environments, but the categorization in this instance is related appreciably with the maturity of the variety and the fact that an early frost was a prime contributing factor to the unfavorable environmental conditions. Results from the other seven environments indicate that Norghum would qualify as a stable variety as described by Scott (1967). It exhibited little variation in performance over a series of environments, and did not respond to the high yield potential of favorable environments.

The analysis used also made possible the identification of entries that are specifically adapted to favorable environments. Entries of this type should have a low mean yield relative to other entries over all environments, a high regression coefficient and sizeable deviations from regression. In this experiment the entry which best fits this category is the hybrid Redlan x Caprock. Its overall mean yield is slightly greater than the experimental mean, it has a regression coefficient significantly greater than unity and deviations from regression that are different from zero at the one per cent level of probability. It was the highest yielding entry at only one environment (Environment 5). The mean yield for all entries was highest in this test and it was considered to be the most favorable environment. The Redlan x Caprock hybrid, however, may not have expressed its full yield potential at some of the unfavorable environments because it is late maturing and the short grain filling period did not permit fullest development of the seed at the environments where early frost was encountered.

From reflections on the relative diversity of the genetic complement of the four population types one might anticipate that a single cross hybrid would be the population type most likely to be specifically adapted to a favorable environment. The Redlan x Caprock hybrid apparently possessed the specific combination of genetic factors necessary for a high response to the favorable conditions of Environment 5, yet it lacked the buffering capacity needed for a high level of performance at all environments.

There are a number of entries which could be considered as stable and adapted to all the environments of this study. Two examples from the hybrid blends are the mixtures of Kafir 60 x Tx 7078 with Martin x Caprock and Redlan x Plainsman with Kafir 60 x Norghum. Examples from the single cross hybrid group are Martin x Tx 7078, Kafir 60 x Tx 7078 and Kafir 60 x Caprock. The mean yields of all of these entries are relatively high, they possess regression coefficients not different from unity, and their deviations from regression are low and not statistically different from zero.

Both of the hybrid blends cited are composed of an early to medium maturing hybrid and a medium late or late maturing hybrid. In unfavorable environments where fertility, length of the growing season or other factors may be limiting the early component may still perform relatively well and thereby compensate for the less than maximum performance of the late component. In the more favorable environments presumably the blend benefits from a high level of performance of both components.

Unlike the hybrid which was specifically adapted to a favorable environment, the hybrid blends cited apparently possess not only the genetic factors which enabled them to give good yields at the more productive environments but also the buffering capacity to do relatively well at the less favorable environments. The hybrid entries, therefore, must possess an individual buffering capacity as described by Allard and Bradshaw (1964), whereas the hybrid blends could possess either the individual or populational type of buffering or both. This buffering capacity may well be determined by genetic factors other than those which condition yield, with their expression manifested through the ability to make maximum utilization of the existing environment. These hybrid blends exemplify the type of stability described by Scott (1967) whereby an entry does not change in its performance relative to other entries when tested in many environments.

The three hybrids that showed considerable stability over all the environments are either medium early or only mid-late in maturity. This may have contributed appreciably to their uniformly good productivity at all environments in that their performance was not reduced by stress factors or other conditions which adversely affected the very early or late entries. With the exception of Kafir 60 x Tx 7078, which was highest in yield in one environment, they were never the highest yielding entry in any single environment.

It is noteworthy that, with one exception, the parental combinations cited for their stability of performance in this investigation, either as hybrids or hybrid blends, have been released as commercial hybrids and grown over a considerable part of the Midwest. Only the Redlan x Plainsman combination has not been released as an experiment station hybrid. Kafir 60 and Tx 7078 are the parents of RS 610, one of the most widely grown and productive hybrids available, and the Martin x Tx 7078 combination is RS 608, another extensively grown hybrid. Kafir 60 x Norghum (RS 501), Kafir 60 x Caprock (Texas 660) and Martin x Caprock (RS 661) have all been grown on appreciable acreages in some sorghum production areas.

A primary objective of this study was to determine which of the population types was the most stable and best adapted across a range of environments. Based on the analysis presented for grain yield, the hybrid blends appear to be the most stable population type. The hybrid blends are both heterozygous and heterogeneous and their performance in this investigation tends to add support to the theories that heterozygotes are more stable than homozygotes, and that heterogeneous populations are better buffered against environmental variations than are homogeneous populations. It is true that the deviations from regression were significantly greater than one for the hybrid blends but this was true for all populations studied. Although the hybrid blends did not display as small deviations from regression as did the parental blends they had a markedly higher mean yield and a regression coefficient not significantly different than 1.0. Thus, none of the population types was distinctly superior for all three stability parameters, and guidelines are not clearly defined for relative weighting of the parameters in making evaluations for stability. Mean yield was highest for the hybrid blends and they had the second best values for the other stability parameters. Therefore, the conclusion that hybrid blends best fit the concept of a stable population as described for this investigation seems justifiable.

Evaluations for stability of performance seem most relevant for total grain yield, but the estimates presented for the primary components of yield also warrant consideration. For heads/plant the means over all environments favor either the hybrids or hybrid blends as the most stable population, whereas on the basis of regression coefficients the hybrids are slightly superior to the other populations. However, the hybrid populations have the largest deviations from regression. Comparisons of the various stability parameter and population combinations for this character do not reveal a consistent or clear superiority for any of the population types. However, the variability exhibited among population types and among environments was low and this result is not surprising.

For seeds/head the hybrids exhibited the greatest stability based on a combined evaluation of the means and regression coefficients, but the deviations from regression favor the parental blends. The data for 100-seed weight again favors the hybrid blends as the most stable population type. They displayed the highest mean and smallest deviations from regression, and had the second best regression coefficient.

While the stability parameters for the individual yield components are not in complete harmony and are not always in agreement with those presented for grain yield, they tend collectively to support the conclusion made from the yield data that the hybrid blends displayed the greatest stability among the types of populations evaluated in this study.

When the blends are compared collectively with the parental and hybrid populations (Tables 22-25) the blended or heterogeneous populations yielded 101.5 per cent of the homogeneous populations. However, in some environments the blends were inferior to the composite performance of the homogeneous populations. Productivity of the three environments where a relatively inferior yield of the blends was obtained represented nearly the entire range of environments. The greatest advantage for blends in this experiment was shown at Environment 3. A heavy infestation of weeds developed in this test in late summer and considerable stress was exerted on the sorghum plants through competition for moisture and nutrients during a part of the growing season. Thus, the performance shown for blends in this investigation is not in agreement with the data reported by Ross (1965). He found only one season in a five year study where the mean of the hybrid blends was significantly greater than the mean of all hybrids. This superiority was exhibited in a season that was characterized as extremely favorable for grain sorghum production. For the five year period only one of the ten blends in the experiment had a mean yield that was significantly greater than the mean performance of the hybrids.

The among populations comparisons showed that parental lines had the lowest and hybrid blends the highest mean yield over all environments. Each parental line was represented equally within the parental and parental blend populations and each hybrid was represented equally within the hybrid and hybrid blend populations. Therefore, the mean of the homogeneous populations (parentals and hybrids) should equal the mean of the heterogeneous populations (parental blends and hybrid blends) if blending has no effect. If an enhancement for yield is shown for the blends then the conclusion that heterogeneous populations are more highly buffered against fluctuations of the environment than are the homogeneous populations would appear to be valid. Support for this conclusion is indicated by the means over all environments (Tables 22-25) which show that the heterogeneous populations had a slight advantage for yield and 100-seed weight.

The comparison of hybrids with hybrid blends is again a comparison based on equal representation of each hybrid within each population group and the mean yields for the two populations should be the same if the heterogeneous or blended populations have no advantage. For both yield and 100-seed weight, the hybrid blends performed better than did the hybrids grown in pure stands. These results provide additional evidence that a favorable response is attained by blending to produce heterogeneous populations.

The results of this experiment indicate that certain lines and hybrids may perform more effectively than others in blended populations. If there is an advantage from blending, one would expect the yield of a blend to surpass the mean yield of its components. In this investigation approximately two-thirds of the blends had yields superior to the mean of their components. Among the parental blends, for instance, every blend having Norghum as a component yielded more than the mean of the components. This performance may be associated with either the extremely low yield of Norghum in pure stands or with its competitive ability in mixtures. Norghum is an exceptionally early line and it may be that it has developed beyond the stage where it provides appreciable competition at the time the other component most needs nutrients and moisture to assure a full development of the grain and maximum expression of its yield potential. Also, each parental blend that contained Westland as a component out yielded the mean of its components. Westland is a medium maturity type so the explanation for the performance of blends involving Norghum generally cannot be applied to the blends in which Westland is a component. However, it may be applicable as an explanation for the relatively better performance of Westland in blends with the late maturing lines Plainsman and Caprock than with other lines. Morphological differences in the structure or development of roots or other parts of the component plants of a blend also may be interactive in determining how well the population performs.

The foregoing comments relative to the performance of parental blends should apply equally well for hybrid blends. For either type of population there is a need for research directed towards determining what plant characteristics exert the greatest competitive effects in heterogeneous mixtures. Investigations comparing the development of individual plants of hybrids or parental lines in mixed and pure stands should be of value for this purpose.

The preceding paragraphs have dealt with superiority of the blends in relation to the mean of their components. Comments and conclusions were based on the assumption that a 1:1 ratio of the components was attained, although this proportion was not verified for all final stands. Performance of the blends relative to their higher yielding component also was examined (Table 27). Superior performance on this basis must result from an enhancing effect of the blended population. Only a few of the blends exceeded the yield of their high component, and those that did usually combined an early or medium early line or hybrid with a later line or hybrid. The hybrid blend of early maturing Kafir 60 x Norghum and late maturing Redlan x Caprock gave the highest percentage value (108%) of any of the blends, and the mixture of medium maturing Westland with late maturing Plainsman gave the highest value among the parental blends.

The superiority shown for blends in this investigation was not of sufficient magnitude to warrant the generalization that heterogeneous (blended) populations are likely to always yield more than homogeneous (non-blended) populations. However, the indications of higher yield and greater stability of performance for the hybrid blends seem sufficiently clear to stimulate additional research of this type. The blends used in this experiment were composed of varieties and hybrids that were selected for production in pure stands, and many of the blends would be agronomically undesirable from the standpoint of uniformity of height and maturity.

The Kafir 60 x Tx 7078 and Martin x Caprock blend cited previously for stability of performance combines two components that are relatively similar for height but they contrast appreciably for maturity. Both height and maturity are markedly contrasting in the Redlan x Plainsman and Kafir 60 x Norghum blend which also showed high performance and stability. Some of the blended populations involved components that were still more diverse for height, maturity and other characteristics. Even so, the performance of blends as a group in this investigation provides encouragement for the use of heterogeneous populations of grain sorghum.

With an intensified effort grain sorghum breeders should be able to select lines and hybrids specifically suited for use as components of blends and a greater superiority for blends could be achieved. Component lines could be selected which would mature at the same time and grow to an equal height. However, within these limits the breeder may also be able to select for types with different rates for the attainment of different stages of plant development. Selection might be directed toward the development of component lines which differ in the time required from planting to flowering or from flowering to maturity and thereby complement each other in a blended population. Possibly sufficient variation in the root systems of different lines could be found or developed to enable the roots of one component to extract moisture and nutrients close to the soil surface whereas other components would extract moisture and nutrients primarily from greater depths in the soil. Lines with differences in leaf morphology which would complement each other in blended populations might also be sought. With this type of plant engineering perhaps the plant breeder could develop blends which would perform advantageously in both optimum and sub-optimum environments.

The statistical procedures used in this investigation could be used concurrently by the plant breeder in selecting the lines and hybrids that exhibited a high stability of performance. While selection was being directed toward the attributes discussed above the breeder also could yield test a portion of the lines which displayed the best combination of desirable morphological traits. Analysis of the data using the procedures for estimating stability parameters could serve as a valuable aid in the selection program. The evidence for genetic differences in stability of performance is documented both from this investigation with sorghums and other experiments referenced in the literature section. The plant breeder should in time be able to concentrate genetic factors for stability into lines and hybrids specifically suited for production as blends.

The correlation coefficients presented in Table 28 suggest that stability parameters determined for the parents of hybrids or for the components of blends may have value for predicting the relative stability of different hybrids or blends. Best agreement between the values predicted from mid-parent or mid-component performance and those determined from the hybrid or blended populations was shown for the regression coefficients, where all coefficients were sizeable and highly significant. The correlations for mean yield showed greater variability. For hybrid blends a good agreement between the two estimates was shown, but the coefficient for parental blends was moderate in size and exceeded only the five per cent level of probability. The relatively low correlation of mid-parent and hybrid yield was not significant. The coefficients for deviations from regression indicated a good agreement between mid-parent and hybrid values, but low correlations were shown for both types of blended populations in relation to the performance of their components. Collectively, the correlations indicate that predictions of stability parameters, especially the regression coefficient, from parental or component performance may serve effectively in the development of stable hybrid or blended populations. In the development of stable hybrids, predictions for the regression coefficient and deviations from regression would appear to be most useful, while predictions for mean yields and regression coefficients were indicated to be most valuable for the blended populations.

The results of this investigation indicated that hybrid blends were the most stable and productive of the populations evaluated and that the parental lines were the least stable and productive. This relative performance is in agreement with several investigations reported in the literature section which propose that heterozygous and heterogeneous populations should exhibit greater stability over a range of environments than populations which are homozygous and homogeneous. In some countries where grain sorghum is used for human food and where production varies markedly from year to year the stability of hybrid blends could be a particularly valuable feature. Facilities are not available for storage of sizeable quantities of surplus grain produced in favorable years and production in unfavorable years may not be sufficient to prevent hunger or starvation. The use of hybrid blends, or even pure line blends where the agriculture is not sufficiently developed to produce hybrid seed, could provide a much needed stabilization of production from year to year.

The stabilizing effect of heterogeneous populations may be of lesser importance than the increased total production in countries where facilities are readily available for storage of surplus grain. But even in these countries the selection and development of hybrids or lines which exhibit an enhancing effect when grown as blended or heterogeneous populations may contribute materially to a more productive agriculture.

The methods of analysis used in this investigation for evaluating stability of performance should be equally applicable for developing heterogeneous populations which display either of the types of stability described by Scott (1967). To develop populations that exhibit the least variation over all environments the breeder would select hybrids or lines for blending that have a regression coefficient on the environmental index that approaches zero and a relatively low yield potential. In developing populations that do not change their performance relative to other populations when tested in many environments selection would be directed toward component types with regression values near 1.0 and small deviations from regression. Selection could be for either high or low yielding types in providing this type of stability *per se*, but practically one would chose the high yielding component hybrids or lines. The latter type of stability would be more desirable for most areas of the United States, but the first type may have value in areas or countries where stress from drought or a low level of productivity is frequently encountered.

SUMMARY

Replicated trials of eight parental lines, 16 single cross hybrids, 16 two-component blends of parental lines, and 16 two-component hybrid blends of grain sorghum were conducted over a two year period in Iowa at a total of nine environments. A wide range in productivity was represented among the environments with environmental mean yields ranging from a low of 63.6 to a high of 117.5 bushels/acre.

Conventional analyses of variance were calculated for yield and yield component data in addition to performing the analyses described by Eberhart and Russell (1966) for the estimation of three stability parameters (entry mean over all environments, regression coefficient upon the environmental index and deviations from regression) for each entry and each of the four population types. A stable entry was defined as one which had a regression coefficient of 1.0, deviations from regression near zero and a high mean yield.

A hybrid was the highest yielding entry in all environments except one, where a hybrid blend was highest in grain yield. Also, the highest mean yield over all environments was exhibited by a hybrid, although it was only slightly more productive than one of the hybrid blends. The lowest yielding entry over all environments was a parental line. Mean yields for each population type over all environments indicated that hybrid blends were the most productive followed in order by

hybrids, parental blends and parental lines.

Genetic differences among the entries were indicated for all characters except seeds/head by variance analyses that combined the data from all environments. Within the population groups parentals and parental blends displayed significant genetic differences for yield and 100-seed weight, whereas differences among hybrids were significant for all characters and hybrid blends displayed significant differences only for 100-seed weight.

Stability parameters estimated for individual entries indicated that certain entries gave a stable performance over all the environments of this investigation, that others were specifically adapted for production in favorable environments and that some were not well adapted for production in most of the environments. The parental entry Norghum appeared to be unadapted to most of the environments as exemplified by its low mean yield and regression coefficient together with high deviations from regression. The hybrid Redlan x Caprock was delineated as an entry specifically adapted for production in favorable environments. It was the highest yielding entry only in the most favorable environment, and had a relatively low mean yield together with a high regression coefficient and significant deviations from regression.

Several entries exhibited stability for grain yield over all environments of this study. Two hybrid blends and three hybrids fit the definition of a stable type particularly well in that they displayed relatively high mean yields, regression coefficients not different from unity and low deviations from regression. These entries generally consisted of parental combinations that have been released as experiment station hybrids and grown on appreciable acreages in sorghum producing areas of the Midwest.

Comparisons for yield among the four population groups indicated that the hybrid blends as a group were the most stable in performance, although none of the population types was distinctly superior for all three stability parameters. Parental lines were the least stable and productive of the population groups. While stability parameters for the individual components of yield were not in complete agreement with those presented for grain yield they tended collectively to support the conclusion that hybrid blends were the most stable population type. These findings lend support to theories of population structure which propose that populations which are both heterozygous and heterogeneous should be the most stable and homozygous-homogeneous types the least stable in production over a range of environments.

Yields of the parental and hybrid blends at the individual environments ranged from 61 to 124 per cent of their expected yield based on the pure stand yield of their components. Across all environments 22 of the 32 blended populations yielded more than the mean of their components. When the blends were compared collectively with the parental and hybrid populations the blended or heterogeneous populations yielded 101.5 per cent of the homogeneous populations. Only five of the blends exceeded the mean pure stand yield of their more productive component.

Correlations of stability parameters predicted from mid-parent or mid-component values with those determined from yields of the hybrids or blends indicated that the predicted values may serve effectively in the development of stable populations. In the development of stable hybrids, predictions for the regression coefficient on the environmental index and deviations from regression would appear to be most useful, while predictions for mean yields and regression coefficients were indicated to be most valuable for the blended populations.

While favorable responses from blending were observed in this investigation, the results were not sufficiently extensive or distinct to merit the generalization that hybrid blends of grain sorghum should be universally superior to the other types of populations in stability and productivity. However, the results are sufficiently conclusive to stimulate additional research on the performance and composition of heterogeneous sorghum populations. Intensified efforts could well be directed toward determining what morphological and developmental features of component lines would enable them to most effectively complement each other when grown in blended populations. By directing their selection towards hybrids specifically suited for use as components of heterozygous and heterogeneous populations plant breeders may be able to develop hybrid blends which would have the yield potential and buffering capacity to perform advantageously in both optimum and suboptimum environments.

LITERATURE CITED

Allard, R. W. 1961. Relationship between genetic diversity and consistency of performance. Crop Science 1: 127-133.

Allard, R. W. and A. D. Bradshaw. 1964. Implications of genotype-environmental interactions in applied plant breeding. Crop Science 4: 503-507.

Bradshaw, A. D. 1965. Evolutionary significance of phenotypic plasticity in plants. Advances in Genetics 13: 115-155.

Burton, G. W. 1948. The performance of various mixtures of hybrid and parent inbred pearl millet, Pennisetum glaucum (L.) R.Br. American Society of Agronomy Journal 40: 908-915.

Byth, D. E. and C. R. Weber. 1968. Effects of genetic heterogeniety within two soybean populations. I. Variability within environments and stability across environments. Crop Science 8: 44-47.

Eberhart, S. A. and W. A. Russell. 1966. Stability parameters for comparing varieties. Crop Science 6: 36-40.

Engelke, H. 1935. Versuche mit Weizenmischsaaten. Journal für Landwirtschaft 83: 61-86. Original available but not translated; cited by Frankel, O. H. 1939. Analytical yield investigations on New Zealand wheat. IV. Blending varieties of wheat. Journal of Agricultural Science 29: 249-250.

Finlay, K. W. 1963. Adaptation - its measurement and significance in barley breeding. International Barley Genetics Symposia, Barley Genetics I, Wageningen, Proceedings 1: 351-359.

Finlay, K. W. and G. N. Wilkinson. 1963. The analysis of adaptation in a plant-breeding programme. Australian Journal of Agricultural Research 14: 742-754.

Frankel, O. H. 1939. Analytical yield investigations on New Zealand wheat. IV. Blending varieties of wheat. Journal of Agricultural Science 29: 249-261.

Frey, K. J. and U. Maldonado. 1967. Relative productivity of homogeneous and heterogeneous oat cultivars in optimum and suboptimum environments. Crop Science 7: 532-535.

Funk, C. R. and J. C. Anderson. 1964. Performance of mixtures of field corn (Zea mays L.) hybrids. Crop Science 4: 353-356.

Gustafsson, Å. 1953. The cooperation of genotypes in barley. Hereditas 39: 1-18.

Jensen, N. F. 1952. Intra-varietal diversification in oat breeding. Agronomy Journal 44: 30-34.

Jones, D. F. 1958. Heterosis and homeostasis in evolution and in applied genetics. American Naturalist 92: 231-238.

Lerner, I. M. 1954. Genetic homeostasis. John Wiley and Sons, Inc., New York, New York.

Lewis, D. 1954. Gene-environment interaction: A relationship between dominance, heterosis, phenotypic stability, and variability. Heredity 8: 333-356.

Lewontin, R. C. 1957. The adaptations of populations to varying environments. Cold Spring Harbor Symposia on Quantitative Biology 22: 395-408.

Mumaw, C. R. and C. R. Weber. 1957. Competition and natural selection in soybean varietal composites. Agronomy Journal 49: 154-160.

Nuding, J. 1936. Leistung und Erbragsstruktur von Winterweizensorten in Reinsaat und Mischung in verschiedenen Anbaugebieten. Pflanzenbau 12: 382-447. Original available but not translated; cited by Frankel, O. H. 1939. Analytical yield investigations on New Zealand wheat. IV. 29: 250.

Patterson, F. L., J. F. Schafer, R. M. Caldwell, and L. E. Compton. 1963. Comparative standing ability and yield of varietal blends of oats. Crop Science 3: 558-560.

Pfahler, P. L. 1964. Fitness and variability in fitness in the cultivated species of Avena. Crop Science 4: 29-31.

Pfahler, P. L. 1965. Environmental variability and genetic diversity within populations of oats (cultivated species of Avena) and rye (Secale cereale L.). Crop Science 5: 271-275.

Plaisted, R. L. and L. C. Peterson. 1959. A technique for evaluating the ability of selections to yield consistently in different locations or seasons. American Potato Journal 36: 381-385.

Probst, A. H. 1957. Performance of variety blends in soybeans. Agronomy Journal 49: 148-150.

Quinby, J. R. and R. E. Karper. 1954. Inheritance of height in sorghum. Agronomy Journal 46: 211-216.

Ross, W. M. 1965. Yield of grain sorghum (Sorghum vulgare Pers.) hybrids alone and in blends. Crop Science 5: 593-594.

Roy, S. K. 1960. Interaction between rice varieties. Journal of Genetics 57: 137-152.

Russell, W. A. and S. A. Eberhart. 1968. Testcrosses of one- and two-ear types of corn belt maize inbreds. II. Stability of performance in different environments. Crop Science 8: 248-251.

Sakai, K. I. 1955. Competition in plants and its relation to selection. Cold Spring Harbor Symposia on Quantitative Biology 20: 137-157.

Schmalhausen, I. I. 1949. Factors of evolution. Blakiston Co., Philadelphia, Pa. Original not available; cited by Lerner, I. M. 1954. Genetic homeostasis. John Wiley and Sons, Inc., New York, New York. 100.

Scott, G. E. 1967. Selecting for stability of yield in maize. Crop Science 7: 549-551.

Shaalan, E. G., E. G. Heyne, and J. R. Lofgren. 1966. Mixtures of hard red winter wheat cultivars. Agronomy Journal 58: 89-91.

Shank, D. B. and M. W. Adams. 1960. Environmental variability within inbred lines and single crosses of maize. Journal of Genetics 57: 119-125.

Simmonds, N. W. 1962. Variability in crop plants, its use and conservation. Biological Review 37: 422-465.

Smith, R. R., D. E. Byth, B. E. Caldwell, and C. R. Weber. 1967. Phenotypic stability in soybean populations. Crop Science 7: 590-592.

Steele, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Company, Inc., New York, New York.

Stringfield, G. H. 1959. Performance of corn hybrids in mixtures. Agronomy Journal 51: 472-473.

Williams, W. 1960. Relative variability of inbred lines and F_1 hybrids in *Lycopersicum esculentum*. Genetics 45: 1457-1465.

Yates, F. and W. G. Cochran. 1938. The analysis of groups of experiments. Journal of Agricultural Science 28: 556-580.

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APPENDIX

Legend of Symbols for Appendix Tables

P Parentals
1 Martin
2 Kafir 60
3 Westland
4 Redlan
5 Tx 7078
6 Caprock
7 Plainsman
8 Norghum

H Hybrids
9 Martin x Tx 7078
10 Martin x Caprock
11 Martin x Plainsman
12 Martin x Norghum
13 Kafir 60 x Tx 7078
14 Kafir 60 x Caprock
15 Kafir 60 x Plainsman
16 Kafir 60 x Norghum
17 Westland x Tx 7078
18 Westland x Caprock
19 Westland x Plainsman
20 Westland x Norghum
21 Redlan x Tx 7078
22 Redlan x Caprock
23 Redlan x Plainsman
24 Redlan x Norghum

PB Parental blends
25 Martin + Tx 7078
26 Martin + Caprock
27 Martin + Plainsman
28 Martin + Norghum
29 Kafir 60 + Tx 7078
30 Kafir 60 + Caprock
31 Kafir 60 + Plainsman
32 Kafir 60 + Norghum
33 Westland + Tx 7078
34 Westland + Caprock
35 Westland + Plainsman
36 Westland + Norghum
37 Redlan + Tx 7078
38 Redlan + Caprock
39 Redlan + Plainsman
40 Redlan + Norghum

HB Hybrid blends
41 Martin x Norghum + Redlan x Tx 7078
42 Redlan x Tx 7078 + Westland x Plainsman
43 Westland x Plainsman + Westland x Tx 7078
44 Westland x Tx 7078 + Westland x Norghum
45 Westland x Norghum + Kafir 60 x Plainsman
46 Kafir 60 x Plainsman + Martin x Tx 7078
47 Martin x Tx 7078 + Westland x Caprock
48 Westland x Caprock + Redlan x Norghum
49 Redlan x Norghum + Kafir 60 x Tx 7078
50 Kafir 60 x Tx 7078 + Martin x Caprock
51 Martin x Caprock + Redlan x Plainsman
52 Redlan x Plainsman + Kafir 60 x Norghum
53 Kafir 60 x Norghum + Redlan x Caprock
54 Redlan x Caprock + Martin x Plainsman
55 Martin x Plainsman + Kafir 60 x Caprock
56 Kafir 60 x Caprock + Martin x Norghum

Table 29. Entry mean yield in grams/plot at each environment

Entry	Environment 1	2	3	4	5	6	7	8	9
P									
1	3361	2139	1945	2723	3777	2630	3139	1922	1659
2	3677	2401	2099	2553	3147	2435	2977	1605	1866
3	2763	1973	1608	2438	2706	2231	2676	1760	1224
4	3199	2452	2169	3234	4297	2419	3566	1313	1781
5	3277	2077	1960	2102	2994	2536	2923	1676	1628
6	3444	2085	2394	2443	3470	2243	3168	954	1122
7	3269	2716	1503	2122	2885	2516	3161	1821	1546
8	2269	1929	810	1753	2181	2033	2650	2422	2003
H									
9	3781	2739	2748	2826	3855	3416	3584	2445	2401
10	3791	2501	2947	3195	4212	2922	3280	2309	1848
11	3494	2695	1894	2810	3718	2788	3285	2352	1998
12	2400	2390	2424	2921	3567	2928	3486	3170	2786
13	3959	3081	2570	3414	3766	3480	3769	2773	2516
14	3922	2934	2935	3091	4218	3196	3554	2077	2431
15	3625	2854	2329	2924	3603	2987	3486	2160	2032
16	2813	2307	2162	2965	3850	3304	3629	3266	2897
17	3789	2663	1968	2869	3414	2974	3329	2090	1919
18	3961	2367	2244	2953	3287	2908	3179	2224	2123
19	3303	2417	1920	2398	3194	2506	3171	2257	1515
20	3216	2475	2489	2831	3382	2779	3701	3648	2503
21	4553	2950	3456	3522	4062	2926	4046	2191	2478
22	3811	2357	3010	3503	4647	2815	3876	1598	1374
23	3691	3093	2474	3039	3781	2861	3594	1715	2070
24	3442	2644	2555	2910	4629	3148	3935	3540	3012
PB									
25	3207	2160	2111	2344	3314	2548	2952	1397	1567
26	3379	2496	2551	2500	3770	2587	3048	1273	1564
27	3089	2189	2237	2516	2331	2414	3366	1874	1297
28	2752	2262	1688	2193	2971	2381	2821	1851	1998
29	2790	2286	1773	2578	3214	2599	3192	1431	1439
30	3311	2279	2446	2567	3212	2429	2843	1290	1717
31	3022	2229	1569	2571	3245	2489	2819	1733	1573
32	2906	2072	1741	2348	3938	2517	2978	2034	2136
33	3158	1993	1877	2469	3261	2360	2557	1759	1530
34	3555	2206	2395	2493	3455	2287	2966	1236	1376

Table 29 (Continued)

	Environment								
Entry	1	2	3	4	5	6	7	8	9
35	3105	2227	1805	2305	3233	2430	2523	1508	1177
36	2644	1813	1340	2180	2898	2084	2746	1864	1417
37	3343	2096	2272	2488	3778	2449	2854	1704	1617
38	3575	1913	2265	2941	4044	2256	3445	1030	1022
39	3623	2509	2312	2704	3906	2386	3095	1108	1682
40	3307	2047	2140	2802	4031	2544	2955	1930	1345
HB									
41	3504	2374	3200	3088	3638	3083	3995	1933	2215
42	3573	2727	2871	2839	3827	3092	3599	1982	2377
43	2940	2203	2443	2744	3643	2500	3277	2207	1877
44	3663	2752	2140	2879	3657	2900	3837	2752	2603
45	3707	2414	2176	2861	3628	3095	3811	2924	2360
46	3792	2608	2323	3014	3722	3137	3583	2342	2556
47	3424	2633	2357	3019	3726	3082	3322	1972	2338
48	3810	2808	2777	3008	4164	3059	3473	3006	2213
49	3643	2477	3037	3207	4345	2924	4001	3357	3050
50	4094	2461	2902	3394	4467	3135	3596	2579	2288
51	3770	2660	1817	2805	4249	2892	3520	2153	2491
52	3795	2797	2422	3027	3917	3139	3740	2577	2379
53	4307	2696	3072	3375	4475	3118	3668	2421	2224
54	2946	2789	3096	3061	4051	2924	3393	1826	1888
55	3318	2757	2682	2915	4229	2978	3430	2486	2212
56	3161	2358	2608	3042	4105	2989	3586	3008	2478

Table 30. Mean number of heads/plant for each entry at each environment

	Environment								
Entry	1	2	3	4	5	6	7	8	9
P									
1	1.035	0.985	1.095	1.005	1.025	1.005	1.055	1.015	1.065
2	1.185	1.035	1.075	0.985	1.005	1.030	1.045	1.040	0.990
3	0.990	1.000	1.065	1.015	0.990	1.020	1.025	1.015	1.015
4	1.035	1.010	1.045	1.030	1.005	1.015	1.045	0.990	1.025
5	1.055	1.025	1.060	0.930	1.045	1.120	1.120	1.010	1.030
6	1.070	0.975	1.130	0.950	1.010	1.035	1.035	1.010	1.000
7	1.200	1.020	1.140	0.930	0.985	1.145	1.160	1.010	1.080
8	1.315	1.050	1.270	1.195	1.425	1.385	1.190	1.220	1.210
H									
9	1.065	0.980	1.140	1.045	1.085	1.070	1.055	1.010	1.025
10	1.125	1.005	1.125	0.975	1.050	1.050	1.035	1.000	1.065
11	1.065	1.000	1.270	0.985	1.065	1.065	1.015	1.080	1.050
12	1.215	1.015	1.385	1.090	1.340	1.230	1.135	1.035	1.050
13	1.160	1.000	1.250	0.985	1.075	1.015	1.065	1.070	1.030
14	1.055	1.010	1.055	1.015	1.010	1.035	1.060	1.000	1.025
15	1.150	0.990	1.095	0.980	0.995	1.040	1.070	1.020	1.010
16	1.145	1.000	1.390	1.095	1.360	1.120	1.070	1.050	1.075
17	1.080	1.000	1.170	1.075	1.040	1.060	1.075	1.000	1.010
18	1.095	1.015	1.090	1.035	1.000	1.075	1.010	1.015	1.030
19	1.020	1.000	1.315	0.895	1.020	1.055	1.075	1.035	0.995
20	1.155	1.030	1.550	1.045	1.505	1.105	1.180	1.065	1.145
21	1.120	1.040	1.155	0.960	1.050	1.025	1.090	1.040	1.015
22	1.025	0.995	1.160	0.940	1.035	1.050	1.050	1.010	1.015
23	0.990	1.035	1.155	0.995	1.000	1.000	1.010	1.030	0.965
24	1.275	1.020	1.225	1.080	1.435	1.145	1.140	1.030	1.135
PB									
25	1.085	1.000	1.220	1.020	1.090	1.075	1.060	1.030	1.060
26	1.040	0.990	1.135	1.025	1.045	1.035	1.070	1.000	1.085
27	1.140	0.980	1.155	1.055	0.975	1.030	1.145	1.030	1.025
28	1.130	1.025	1.130	1.025	1.130	1.120	1.160	1.170	1.215
29	1.070	1.010	1.050	1.015	1.030	1.055	1.125	0.990	1.035
30	1.095	1.015	1.060	0.985	1.035	0.990	1.105	0.990	1.105
31	1.070	0.985	1.095	1.025	1.015	1.010	1.115	1.015	1.020
32	1.165	1.085	1.210	1.035	1.135	1.195	1.210	1.055	1.080
33	1.065	1.005	1.060	1.065	1.035	1.055	1.115	1.010	1.000

Table 30 (Continued)

Entry	Environment 1	2	3	4	5	6	7	8	9
PB (continued)									
34	1.055	1.045	1.075	0.975	1.000	1.060	1.055	1.005	1.000
35	1.175	0.985	1.040	1.050	1.035	1.035	1.030	1.015	1.070
36	1.220	1.020	1.145	1.030	1.245	1.190	1.115	1.035	1.095
37	1.135	1.000	1.075	0.985	1.080	1.050	1.070	1.010	1.000
38	1.030	1.000	1.075	1.020	1.090	1.025	1.025	0.960	1.015
39	1.045	1.015	1.130	0.960	1.015	1.035	1.055	1.025	1.035
40	1.220	1.015	1.305	1.045	1.060	1.190	1.085	1.065	1.060
HB									
41	1.090	1.010	1.320	0.985	1.185	1.050	1.085	1.015	1.040
42	1.095	1.005	1.170	0.980	1.015	1.125	1.050	1.020	1.045
43	1.015	1.000	1.160	0.930	1.040	1.015	1.040	0.985	1.000
44	1.165	1.020	1.260	1.010	1.155	1.065	1.180	1.065	1.030
45	1.180	1.020	1.195	1.040	1.295	1.130	1.095	1.020	1.085
46	1.090	0.985	1.150	0.995	0.990	1.075	1.055	1.000	1.065
47	1.020	1.000	1.260	0.995	0.990	1.025	1.055	1.000	1.035
48	1.220	1.055	1.305	1.110	1.370	1.090	1.170	1.020	1.010
49	1.140	1.010	1.210	1.145	1.330	1.165	1.185	1.020	1.030
50	1.125	0.930	1.095	1.005	1.005	1.030	1.020	1.025	1.010
51	1.140	0.990	1.135	0.975	1.040	1.030	1.090	1.005	1.020
52	1.215	1.020	1.255	0.955	1.050	1.070	1.055	1.070	1.000
53	1.150	0.990	1.300	1.000	1.110	1.095	1.055	1.045	1.045
54	1.040	0.990	1.095	0.960	1.065	1.085	1.090	1.000	1.090
55	1.095	0.985	1.185	0.915	1.080	1.030	1.040	1.030	1.010
56	1.180	1.000	1.350	1.025	1.130	1.100	1.055	1.085	1.025

Table 31. Mean number of seeds/head for each entry at each environment

	Environment								
Entry	1	2	3	4	5	6	7	8	9
P									
1	2156	1774	1457	1921	2279	2117	2096	2416	1823
2	1573	1674	1184	1653	1824	2086	2122	2289	2049
3	1806	1496	1056	1459	1533	1875	1989	2366	1081
4	1818	1806	1175	1746	1951	1961	2201	2068	2140
5	1881	1498	1483	1669	1869	2157	2246	2340	1593
6	2120	2077	1538	1862	2210	2514	2706	2208	1725
7	1897	2278	1232	2200	2003	2606	2288	2558	1679
8	1101	1340	692	1094	1054	1130	1595	1667	1139
H									
9	2115	2056	1953	1889	2246	2340	2490	2820	2147
10	2196	2197	1917	2304	2290	2393	2585	2814	2322
11	2099	2235	1562	2219	2458	2399	2542	2685	2344
12	1133	1570	1261	1550	1314	1484	1971	1987	1773
13	1833	2292	1519	2089	2110	2288	2422	2331	2324
14	2067	2314	1652	2003	2311	2307	2349	2615	2197
15	2028	2135	1378	2184	2158	2149	2329	2477	1954
16	1305	1541	1309	1701	1582	1701	2156	2140	1836
17	2148	2077	1527	2038	2242	2796	2593	2414	2303
18	2312	1827	1443	2079	2476	2503	2728	3065	2419
19	2518	2101	1836	2355	2334	2420	2446	3025	2031
20	1479	1523	1151	1547	1427	1647	1873	2270	1772
21	2436	2384	2065	2480	2562	2466	2695	2788	2571
22	2309	2131	1529	2543	2607	2796	2667	2798	2611
23	2830	2444	1351	2362	2874	2694	3286	3438	2757
24	1294	1703	1218	1597	1596	1537	2250	2668	1974
PB									
25	1967	1738	1626	1937	2001	2112	2167	2314	1788
26	2057	2163	1497	1750	2519	2233	2140	2458	1733
27	1679	1863	1656	1786	1904	2095	2176	2272	1735
28	1481	1562	1115	1521	1785	1591	1814	1765	1555
29	1638	1766	1364	1791	1845	2069	2210	2183	1743
30	1955	1946	1390	1793	2177	2348	2156	2009	1768
31	1765	1940	1192	1697	2183	2293	2405	2270	2095
32	1568	1432	973	1507	1670	1665	1901	1907	1621
33	1834	1498	1165	1716	1987	1977	1899	2149	1713

Table 31 (Continued)

	Environment								
Entry	1	2	3	4	5	6	7	8	9
PB (continued)									
34	2138	1823	1764	1776	2205	2185	2252	2293	1761
35	1658	1849	1285	1821	1972	2145	2427	2092	1747
36	1271	1300	826	1398	1584	1448	1695	1767	1425
37	1698	1783	1230	1604	1764	2228	2411	2426	1906
38	2081	1582	1147	1773	2048	2375	2168	2416	1305
39	2029	1922	1114	1806	1881	2001	2134	2025	2169
40	1466	1791	960	1532	1788	1658	2011	1747	1298
HB									
41	1929	1676	1486	1867	1924	2144	2421	2496	1804
42	2259	2080	1754	2215	2148	2469	2940	2899	2659
43	2055	1843	1686	2187	2395	2603	2586	2721	2012
44	1842	1973	1261	2022	1765	2026	2230	2267	1991
45	1645	1804	1281	1692	1680	1916	2126	2047	1905
46	2015	2032	1478	2104	2212	2341	2521	2502	2367
47	2379	2117	1594	2097	2645	2911	2374	2916	2034
48	1662	1813	1331	1914	1552	1912	2210	2447	2074
49	1837	1865	1389	1661	1691	1690	2235	2878	1926
50	2129	2226	1718	2266	2450	2522	2473	2632	2158
51	2302	2276	1523	2130	2638	2479	2692	2973	2802
52	2163	2122	1356	2197	2185	2380	2537	2111	2109
53	1857	2170	1464	2107	2341	2055	2705	2125	1638
54	2224	2296	1772	2183	2288	2590	2579	2690	2331
55	1954	2283	1657	2225	2235	2512	2766	2669	2387
56	1305	1789	1165	1854	1968	1710	2423	2864	2136

Table 32. Mean weight in grams of 100 seeds for each entry at each environment

	Environment								
Entry	1	2	3	4	5	6	7	8	9
P									
1	2.420	1.900	1.870	2.165	2.750	1.965	2.510	1.215	1.435
2	2.850	2.175	2.625	2.325	2.775	1.795	2.265	1.070	1.540
3	2.500	2.045	2.155	2.535	2.765	1.830	2.175	1.155	1.945
4	2.610	2.105	3.170	2.770	3.275	1.880	2.620	1.000	1.320
5	2.475	2.135	2.125	2.215	2.670	1.705	2.280	1.235	1.540
6	2.360	1.610	2.375	2.185	2.625	1.480	1.970	0.645	1.000
7	2.365	2.000	1.780	2.095	2.405	1.465	2.175	1.120	1.250
8	2.425	2.235	1.790	2.365	2.385	2.160	2.335	2.120	2.160
H									
9	2.500	2.065	2.030	2.235	2.640	2.100	2.445	1.500	1.865
10	2.405	1.835	2.315	2.185	2.760	1.880	2.215	1.270	1.250
11	2.485	1.900	1.960	2.060	2.325	1.790	2.120	1.270	1.280
12	2.900	2.475	2.530	2.855	3.005	2.595	2.830	2.385	2.510
13	2.790	2.205	2.325	2.495	2.790	2.365	2.620	1.700	1.825
14	2.835	2.115	2.725	2.500	2.970	2.130	2.455	1.315	1.720
15	2.800	1.995	2.390	2.290	2.605	2.045	2.375	1.350	1.505
16	3.020	2.390	2.525	2.730	3.045	2.735	2.810	2.295	2.555
17	2.480	2.020	1.860	2.180	2.395	1.585	2.005	1.260	1.480
18	2.340	1.895	2.410	2.285	2.440	1.830	2.120	1.205	1.310
19	1.985	1.805	1.930	1.905	2.170	1.535	2.010	1.185	1.165
20	2.905	2.445	2.425	2.760	2.965	2.460	2.765	2.335	2.210
21	2.655	1.980	2.425	2.450	2.570	1.785	2.330	1.260	1.535
22	2.540	1.755	2.765	2.355	2.785	1.665	2.375	0.940	0.890
23	2.325	2.095	2.480	2.230	2.285	1.690	1.955	0.965	1.220
24	3.155	2.390	2.630	2.760	3.240	2.870	2.875	2.290	2.345
PB									
25	2.410	1.920	2.115	2.220	2.650	1.680	2.320	1.175	1.450
26	2.480	1.740	2.370	2.145	2.450	1.840	2.230	1.015	1.355
27	2.470	1.865	2.065	2.185	2.160	1.800	2.360	1.270	1.205
28	2.390	2.145	2.070	2.340	2.595	2.045	2.360	1.535	1.785
29	2.500	2.095	2.160	2.400	2.665	1.905	2.225	1.115	1.290
30	2.415	1.830	2.530	2.255	2.585	1.655	2.190	1.015	1.395
31	2.420	1.965	2.080	2.245	2.510	1.780	2.045	1.190	1.250
32	2.485	2.215	2.340	2.325	2.665	2.035	2.300	1.580	1.845
33	2.460	1.985	2.260	2.460	2.670	1.780	2.160	1.280	1.415

Table 32 (Continued)

Entry	Environment 1	2	3	4	5	6	7	8	9
PB (continued)									
34	2.490	1.845	2.385	2.290	2.465	1.540	2.110	0.900	1.250
35	2.545	1.980	2.115	2.240	2.760	1.765	2.035	1.125	1.195
36	2.920	2.145	2.175	2.440	2.530	1.980	2.420	1.605	1.725
37	2.565	2.050	2.910	2.620	2.980	1.775	2.200	1.100	1.385
38	2.530	1.790	2.940	2.625	3.065	1.470	2.505	0.785	1.140
39	2.685	1.965	2.920	2.560	3.100	1.850	2.395	0.855	1.250
40	2.720	2.000	2.955	2.670	3.365	2.065	2.315	1.590	1.595
HB									
41	2.700	2.240	2.560	2.580	2.790	2.310	2.580	1.945	1.945
42	2.490	1.010	2.395	2.245	2.850	1.715	2.260	1.230	1.590
43	2.190	1.835	1.930	2.070	2.310	1.510	2.045	1.280	1.375
44	2.585	2.180	2.215	2.305	2.885	2.170	2.500	1.825	2.000
45	2.910	2.290	2.325	2.610	2.805	2.280	2.600	2.025	1.990
46	2.675	1.995	2.155	2.405	2.605	2.075	2.390	1.440	1.705
47	2.200	1.890	2.120	2.270	2.695	1.655	2.195	1.100	1.620
48	2.945	2.330	2.535	2.655	3.235	2.355	2.670	1.950	1.770
49	2.815	2.165	1.705	2.885	3.095	2.515	2.730	2.065	2.220
50	2.760	1.880	2.325	2.345	2.740	1.990	2.325	1.485	1.625
51	2.475	1.950	2.125	2.310	2.690	1.740	2.165	1.105	1.505
52	2.620	2.165	2.595	2.420	2.880	2.085	2.365	1.955	2.040
53	3.015	2.060	2.620	2.610	2.905	2.270	2.460	1.835	2.075
54	2.605	1.880	2.425	2.355	2.840	1.745	2.290	1.170	1.270
55	2.480	1.985	2.475	2.170	2.785	1.805	2.300	1.365	1.570
56	3.105	2.170	2.695	2.505	3.050	2.550	2.550	1.775	1.810